Commentary

A STAFF COLLEGE FOR TECHNOLOGISTS

THE Willis Jackson report on *The Supply and Training of Teachers for Technical Colleges* made several recommendations to the Minister of Education, not the least of which was the proposal that a Staff College should be established to provide short residential courses for senior lecturers from technical and commercial colleges. While technical teaching staffs welcomed this idea they wondered if it would ever become a reality, but their doubts have been dispelled by the official announcement not only of the plans in hand for this college but by the news that Sir ALEXANDER FLECK is to be its first chairman, and that he and Sir WILLIS JACKSON are working together in order to bring about its early foundation.

One of the main functions of the Staff College is to bring technical and commercial colleges in closer touch with industry. The Staff College will provide an attractive, residential centre for short conferences where senior teaching staff from technical institutions will meet interested persons from industry and commerce, and where in a leisured atmosphere they will discuss matters of moment in the world of technical teaching. It is to be hoped that the limited numbers attending any one course will help to foster a feeling of co-partnership, and that each participant will become more aware of his responsibility for raising the standards of technological training in this country. It must be emphasized that Staff College is not another name for training college. The art of leadership and wise administration will be its concern, and not the first techniques of class instruction.

The conception of this college is an excellent one. Any action which can be taken to bring industry and appropriate training bodies closer together should be taken. Their close co-operation is needed with regard to the content of syllabuses where courage is called for not only to insist on including the new but in shedding what is no longer required. There are too many people connected with higher education who measure the worth of syllabuses and book lists in terms of their length and not their content. The college could also spend useful time on the question of the division of training between theory and practice and the welding of these two into one whole, and on the research work of the colleges, and the selection and placement of students on courses.

There are some serious problems to be resolved before the Staff College begins to function. It has not been easy in the past to free technical teaching staff from their posts for short refresher periods in industry or for attendance at conferences and courses. Although the Ministry of Education devised a scheme for the return of teaching staff to industry very few were allowed to do this. The success of the Ministry's scheme depended on the good will of industry just as the success of the Willis Jackson college will, and industrial support for the former was disappointingly small. Perhaps the fault lay with the colleges in not making their staff shortages well enough known. There is much to be gained by both sides in the interchange of staff between factory and lecture room, and it is these very teachers who have kept themselves up to date with industrial progress who would have most to give and get from Staff College conferences.

Another problem is one that the Willis Jackson committee raised—the excessive teaching load that individual teachers are asked to carry. It is not unusual for teaching staff in some subjects to be expected to lecture from eighteen to twenty four hours a week. Staff in such a situation have little time to think about what they are doing as they rush like Alice's White Rabbit in a race against the clock. Not for them are the pleasures of careful preparation and the lively presentation of lecture material. While those teachers are not hostile to the idea of the Staff College they have good reason to urge that the stimulation of thought on technological training and the grooming of men to give it vigorous leadership should start at the top. Enlightenment, these critics contend, should spread from the governing bodies downwards, and they use industry as their example where the best firms train first their senior executives.

Yet the Staff College can do a great deal for technical education. The very fact that the college is to be guided by Sir Alexander Fleck will add to its prestige and will surely help to give to technical education the respectability it deserves. The closer the colleges associate with industry the better will be their work. One would like to see them not only sharing the responsibility for the training of scientists, technicians and technologists but working as partners on research projects and on post-graduate courses of the highest level. The composition of the conference with twenty members drawn from colleges and ten from industry and commerce is likely to lead to such activities. At present not enough is known by industry and technical institutions about the work the other does, and it is to be expected that their increasing acquaintance, started in the Staff College, will add to their mutual respect.

S.C.

THE ARITHMETIC OF SAILING

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The author describes the research that has been and is being carried out to improve the design of orthodox yachts and he also makes various suggestions as to the possible direction of future research as regards both the design of normal yachts and the design of other more unusual but more efficient sailing craft.

THE steady encroachment of orthodox science into the lunatic fringe is making it progressively harder for the natural minority-man to find an outlet. From being a pleasant, intellectual diversion for a small group of the nicely mad, space research has, in a decade, developed into a serious business. The latest on the danger-list is the preserve of another small group, revolutionary reactionaries and plain reactionaries, those who want to ginger up sailing and those who are merely curious about the behaviour pattern of the conventional sailing yacht. Now that investigations of the normal yacht have been openly admitted to form part of the research programme of a university department, academic respectability already has one foot in the door. Publicity there must be. Perhaps, if we can show how pedestrian it all is, we may yet preserve a gentlemanly unhaste about the subject.

What, then, are the burning topics? Questions are at last being asked, for one thing, about the validity of the procedure that has been employed in interpreting tank-tests for more than twenty years. The history of this is quickly told.

Tank-Testing and its Interpretation

In the early thirties the late K. S. M. DAVIDSON[1] developed the technique of stimulating turbulence and so obtaining satisfactory agreement between yacht models of different sizes, and between model and full-sized yachts; as a result there was built at Stevens Institute of Technology, Hoboken, New Jersey, a yacht dynamometer such that reliable predictions of resistance at full-scale could be made by use of comparatively small models. Apart from this being the first dynamometer really suited to measuring the lateral forces developed by hulls running in yaw, the small size and relatively low cost of testing have made it possible for a yacht-designer with a not too impoverished client to select one of several designs. A number of designers in America have now acquired experience of judging the results for themselves, and Olin STEPHENS, in particular, has used tank-testing to refine a design; this is clearly an ideal way to use a tank, in contrast to the procedure adopted in preparing the recent, unsuccessful challenge for the America's Cup; one design was chosen from eight models by four designers, with no subsequent refining.

Though yacht-dynamometers are still being improved, and Messrs Saunders-Roe will before long have what may prove to be the most advanced in the world, there is no reason to doubt the observations made with the earlier versions. What has not until now been critically reviewed is the criterion by which hulls are compared, and a paper on this is to be given at the Spring Meeting in 1960 of the Royal Institution of Naval Architects[2]. The criterion has been a set of sail coefficients known as the *Gimcrack* coefficients, and two yachts are judged one against the other by the use of a single curve for each, which is supposedly the best speed made good to windward as a function of the true wind speed. The *Gimcrack* coefficients derive from a yacht of that name, which was tested by DAVIDSON in 1935; measurements of windward performance in full-scale sailing trials were interpreted in terms of heeling and driving forces by means of the predicted resistance at different speeds and several angles of heel.

One assumption that is made when these coefficients are applied to some other vessel under examination is that, if the vessel's angle of heel is kept constant, the rig can be trimmed so as to give the same force coefficient and drag for a reasonable range of the angle β of the apparent wind to the course sailed. *Figure 1* shows forces, speeds and angles for three courses bracketing a maximum in speed made good, subject to these assumptions. What is implied is that the whole structure above water is a single aerodynamic unit which can be rotated about a vertical axis, and is kept at the same attitude to the apparent wind. This is questionable in that, in the first place, something like half the

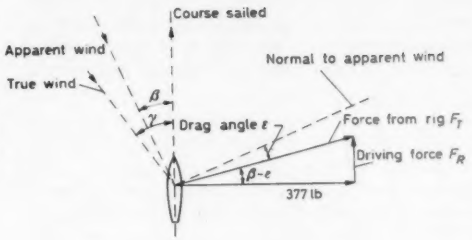

Figure 1. A comparison of three conditions giving a typical yacht the same angle of heel, 26°, and bracketing a maximum in speed made good at constant heel. It is seen that constant heel requires almost the same true wind for all three cases, so that the significant quantity, speed made good at constant true wind speed, has an identical maximum in terms of true course

		22°	24°	26°
Angle of apparent wind to course	β			
Resultant aerodynamic force	F_T	386·3 lb	389·5 lb	393·4 lb
Speed of apparent wind	V_A	15·91 kts	15·98 kts	16·06 kts
Forward thrust	F_R	84·3 lb	98·2 lb	112·4 lb
Yacht's speed	V_S	5·169 kts	5·394 kts	5·590 kts
Angle of course to true wind	γ	31·87°	35·23°	38·52°
Speed of true wind	V_T	11·29 kts	11·27 kts	11·30 kts
Speed made good to windward	$V_S \cos \gamma$	4·390 kts	4·406 kts	4·372 kts

It is assumed that the rig can rotate slightly about a vertical axis with changes of apparent wind, keeping the drag angle ϵ and the force coefficient C_T both constant at 9·4° and 1·00. A lateral force of 377 lb at the centre of effort of the rig gives an angle of heel 26°, so that the force F_T is 377 sec $(\beta-\epsilon)$, and for the chosen sail area, 450 ft², and supposed C_T, $V_A = 0{\cdot}810\sqrt{F_T}$. The forward thrust $F_R = 377 \tan(\beta-\epsilon)$, and the speed V_S follows from this, using the resistance curve for heel 26°. The direction and strength of the true wind are then given by

$$\tan \gamma = \frac{\sin \beta}{\cos \beta - V_S/V_A} \text{ and } V_T = V_A \frac{\sin \beta}{\sin \gamma}$$

drag is due to the windage of the hull, which clearly increases with increasing β, and, in the second place, trimming the sheets does not in fact rotate the rig about a vertical axis.

When an experienced helmsman sails his yacht at its best to windward, his acquired skill is giving him the result of an experiment that could in principle be performed in an ideally steady wind, with the assistance of instruments; sailing on a course of, say, 33° to the true wind, he would adjust the rig to give the maximum speed through the water, regardless of heel; this speed multiplied by the cosine of 33° is then the best speed made good on that course; this is then compared with the best speed made good on courses of 36° and 39° to the true wind, each case having its own best sail trim and in general a different angle of heel. The best true course is then found. Although the helmsman is normally more conscious of the apparent wind than of the real wind, the strength and direction of the apparent wind are better treated as dependent variables.

In order to judge between rival designs, it is clearly necessary to postulate some standard rig, whose forces can be applied to each hull, so that its performance may be predicted with reasonable realism. Hulls do vary, however, in their stability and in the rate at which resistance increases with heel. There is, then, no reason to suppose that there is one angle of the standard rig to the apparent wind that is ideal for every yacht at a given angle of heel, and, furthermore, the comparison, as in the more restricted case of *Figure 1*, of different courses relative to the true wind at constant heel has no meaning if the wind strength has to be assumed to vary appreciably in order to keep the heel constant. It does appear, however, that even when sail trim is included as a variable, this last objection to current procedure may have its sting removed as a result of a curious coincidence. By assuming a more complete set of sail coefficients (*Figure 2*) and including the angle of incidence as a variable on which the force coefficient and drag angle depend, the writer has examined the behaviour to be expected from a hull with the properties of the original *Gimcrack* (*Figure 3*). (The rig is still assumed to be capable of rotating about a vertical axis without change of aerodynamic properties.) When comparison is then made of the speeds made good on different courses in a *constant true wind*, sail incidence being kept continuously at

optimum, it is seen that, over the range of courses around the optimum, the angle of heel will be almost constant (*Figure 4*). This applies to only one hull and one set of reasonably realistic sail coefficients,

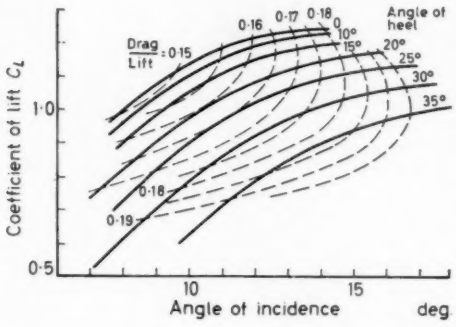

Figure 2. A trial set of sail coefficients based on the data for an aerofoil of aspect ratio 6. 'Lift' is defined here as the force in a horizontal plane. The drag/lift ratio D/L is equal to tan ε, where ε is the drag angle of Figure 1. The C_T of Figure 1 is C_L sec ε. The rig is assumed, in effect, to rotate about a vertical axis

and not enough is yet known to show whether these conclusions have any wider validity. If they are true or nearly true, then the practice of comparing speeds made good at constant heel will introduce less error than might be expected. There is no reason, of course, for retaining this feature of the existing procedure except possibly a small reduction in the time spent in the analysis of a test.

Research on Orthodox Yachts

The average scientist, asked to investigate the performance of a yacht with no experience of this field, would expect to find an accumulation of observations and deductions such as these, but no discussion on these lines has been made public. It will be evident that a number of basic questions have still to be answered, and until the behaviour pattern of the normal yacht has been established the study can hardly be said to have reached maturity. Serious discussion of yacht design cannot begin until there is general agreement on how the variables are interrelated. There may be little enough published on the characteristics of different hulls, and there is certainly a regrettable lack of direct measurements on full-sized sails, but a big step could be made, without further experimenting, by pencil and paper trials, mating known hull properties or variants of these with synthetic sail coefficients devised by analogy from the data of aeronautical engineering.

It seems probable that DAVIDSON adopted the present procedure only after much careful thought and logical argument, of which we will now remain ignorant, and his successors at the Davidson Laboratory have had no reason to be dissatisfied with the working of the current technique. The U.S.A. has, alas, not yet lost the America's Cup. Yacht analysis only forms a small fraction of the work at Stevens Institute, and a revenue of $30,000–50,000 per annum for this particular item has not justified the assignment of staff to a fresh examination of fundamentals.

In Britain we have had shocks that should suffice to rouse us from our inactivity, and there are prospects that we may at last be able to make a useful contribution to the subject. An Advisory Committee for Yacht Research will coordinate a number of projects, including work by Messrs Saunders-Roe and research in the Department of Aeronautical Engineering, Southampton University. Useful amateur work could be, and may yet be done; the Amateur Yacht Research Society, whose activities over the five years of its existence have centred more on qualitative exploration of the unorthodox, is now engaged on building a wind-tunnel for testing dinghy rigs in full-size. An earlier organization which attempted to finance and direct a programme of similar work, employing professional organizations, came to an unhappy end; the Yacht Research Council brought together a number of scientists and experienced yachtsmen, and some

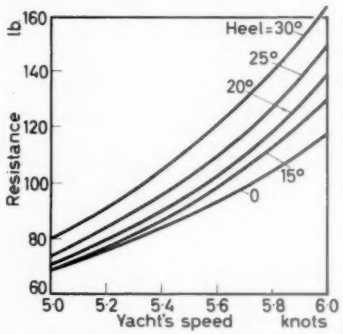

Figure 3. Resistance curves of a typical yacht closely resembling Gimcrack, measurements being made with sufficient yaw to develop a keel force equal and opposite to the heeling force appropriate to a given angle of heel

tank-tests were done, some sailing trials conducted; these may yet provide more information. The sailing trials, in particular, were carried out with an array of instruments greatly exceeding that of the classic

Gimcrack trials, and they should have made it possible to augment or replace the *Gimcrack* coefficients. Being largely concerned with raising the prestige of British yachting and being committed to finding financial support on those grounds, the

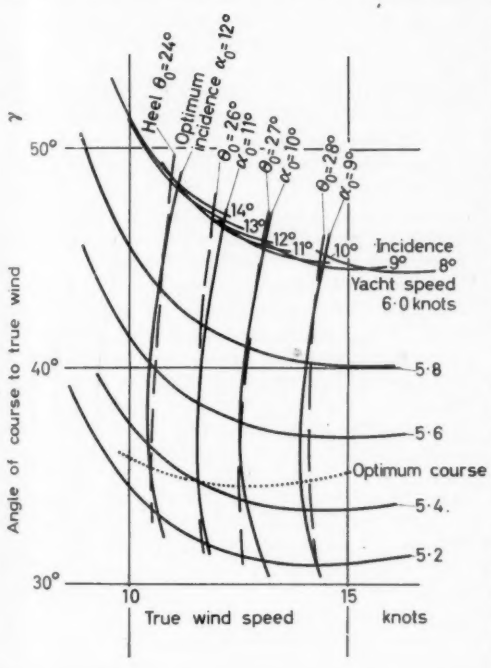

Figure 4. Performance curves of constant yacht speed and constant angle of incidence of the apparent wind on the rig. The envelope of each family of curves represents an optimum, determining the best incidence and the corresponding angle of heel. At any given true wind speed the optimum incidence and optimum heel vary only slightly with change of course angle, particularly when near the course for maximum speed made good to windward

Yacht Research Council felt it necessary to give its two reports a restricted circulation—a regrettable if understandable decision. The subject is still in need of thorough discussion in the open forum, and we cannot but be grateful that Davidson and his school have given us the benefit of a series of Technical Memoranda.

Those who want to reach a better understanding of the yacht, and who want to know, for example, how much has on average to be paid in increased resistance for improved stability resulting from an increase in beam, have no illusion that the scientist is going to replace the artist who draws the lines of these graceful products of an ancient craft. Formulae have, however, to be devised in order to allow a range of designs to race together as a class, either without time allowances, as in the 5·5-Metre class, one of those used in the Olympic Games, and the 12-Metre class, in which the America's Cup is now contested, or as a wider class with handicaps; the ocean-racers are the most important of these. Unless these formulae balance the variables fairly, they may in time bias a whole class towards one extreme or another, developing undesirable trends. This has happened. Such rating-rules are developed empirically, but the life-time of one rule may be 20–50 years, and a new rule will rarely be proved unsatisfactory in much less than 10 years, so that the evolutionary process can draw on too few experiments in a century for its proper operation. Some help should be given by the research now contemplated.

Slow as all these keel yachts are in comparison with what can be done on water by sail, they do represent almost the ultimate in seaworthy, single-hulled craft. As such they are worthy of study, and the fullest development of their potentialities is a challenge.

Unorthodox Sailing Craft

The quest for a more efficient means of exploiting wind power on water has acquired some momentum, but even this is largely a process of empirical development. A paper in 1951[3] analysed the requirements in the way of stability and sail area for the use of planing hulls, and, though a brief survey of the prospects of sailing on hydrofoils was made in 1953[4], many other aspects have still not been given any theoretical examination. Enough is known of the efficiency of windmills for a study to be made of the possibilities of a windmill coupled to a water propeller. *Figure 5* gives an impression of one form into which the ocean-going sailing-ship might have developed if convention had been discarded and modern techniques adopted; the evidence suggests that speeds of 30 knots or more might be obtained with the wind abeam, and speeds to windward of around 20 knots could be maintained in any sea of wave-height less than some 20 feet.

The present popularity of the double canoe or biscaph, misnamed the catamaran, may be a step towards yet faster craft. With its hulls of displacement type, the catamaran is unlikely to develop speeds much higher than those now attained, and only the largest catamarans yet equal the speeds of the canoes of the Pacific, which were fully developed more than three centuries ago, and reached their ultimate in the *Flying Proas* of the Mariana or

Ladrone Islands. Those remarkable craft, which became extinct in the nineteenth century, were reported by Magellan, and in 1686 the Royal Society's only buccaneer, Captain Dampier, sailed in one, and tried to measure its speed with log-line

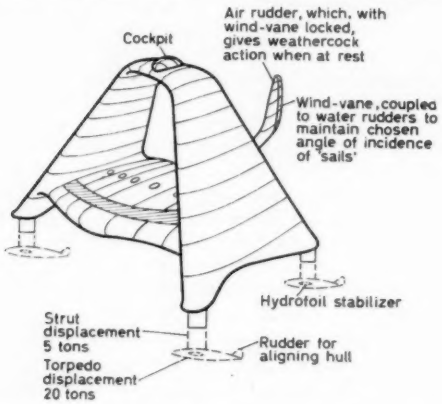
Air rudder, which, with wind-vane locked, gives weathercock action when at rest
Cockpit
Wind-vane, coupled to water rudders to maintain chosen angle of incidence of 'sails'
Hydrofoil stabilizer
Strut displacement 5 tons
Torpedo displacement 20 tons
Rudder for aligning hull

Figure 5. One form of fast passenger-carrying sailing vessel which might have evolved

Capable of averaging under ten days for the Atlantic crossing, and employing a small crew, it would be the ocean-going equivalent of the long-distance coach. The combination of torpedo and strut would give a natural period of about ten seconds for pitch, roll or heave, affording ample hydrostatic stability and yet sufficient independence of most normal waves to allow speeds of 20 knots to be maintained when sailing to windward. The hydrofoils are intended for stabilization and not for lifting the vessel as a whole. Being fast enough to go where the best weather was, it would introduce a new skill into navigation, that of exploiting meteorological information to the limit.

and sand-glass; the limit of this was 12 knots, and Dampier reckoned the sand to be only half run out when the line was fully out. Anson even brought a specimen to Britain, and his observations during his long stay at Tinian led him to report that ' with a brisk trade-wind they will run at near twenty miles an hour '. His historian, the Rev. Richard Walter was filled with admiration for them, and one of his observations is of particular interest, when he comments on their ' running with a velocity nearly as great, and perhaps sometimes greater than what the wind blows with. This, however paradoxical it may appear, is evident enough in similar instances on shore, since it is well known that the sails of a windmill often move faster than the wind.'

Sailing at a speed above the wind speed is still a rarity, and the consistent attainment of this may be taken as the goal for the next phase of development. Undoubtedly the best way of avoiding the severe retarding effects of the seas that normally accompany winds of the order of 20 knots, is to make use of the hydrofoil. The technique of supporting power-driven vessels on hydrofoils has made great advances in the last ten years, and there is one form that appears to be specially well adapted to harnessing the more variable drive from sails, namely the *Hook Hydrofin*, in which fully submerged foils are subject to incidence-control from mechanical feelers; these give the vessel the rise and fall needed to clear larger waves, while ignoring smaller waves that can be cleared in level flight.

The design of a hydrofoil sailing vessel poses some interesting problems. Speeds of 35–40 knots would be possible in winds of about 25 knots, but a vessel intended for maximum top speed would not become foil-borne when the wind was less than about 20 knots. It would then be much slower than one with larger foils and greater sail area per ton, which could leave the surface with a wind as low as 10 knots, but which might not be able to exceed 25 knots. A peculiarity which these craft share with ice-yachts is their liability to blow themselves over with a wind largely of their own making. This is met by spilling wind from the sails and consequently increasing their drag/lift ratio. The hydrofoils also operate less efficiently at the higher speeds, for, if they are of such an area as to support the vessel at, say, 10 knots, then at 30 knots they must reduce their coefficient of lift to one-ninth of that for take-off, and this is far from the condition of minimum drag/lift ratio.

Size of vessel has virtually no effect on top speed when foil-borne, whereas under displacement conditions the advantage goes to the longest hull. It would, therefore, be quite practicable to introduce a new class of entirely unrestricted racing in which the prize would not inevitably go to the deepest purse. Good design combined with skilful handling could win world championships at a cost of well under £1,000.

Until that day comes, the role of science in sailing will be limited to less spectacular but none the less important smaller contributions.

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STUDIES OF FIRES IN BUILDINGS USING MODELS

Part II. Some Theoretical and Practical Considerations

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In Part I of this paper, published in the February issue of RESEARCH, the author described experiments on ignition and fires in rooms. Part II of the paper outlines some theoretical considerations involved in interpreting the experimental results and discusses some of the practical applications of the work. Some measurements of radiation from fires with large openings in the wall are quoted, and an outline is given of a means of correlating the heights of flames from fires in enclosures.

Fire Regulations for Fire-Resistance

IT HAS been shown in Part I of the paper that for fires with low ventilation, the rate of burning is independent of the fire load and for a given degree of ventilation the duration is proportional to the total fire load not the fire load per unit area. This has an important bearing on the present British fire grading of buildings[1] where at present the fire-resistance required of structural elements is based on an estimated fire load per unit area*. However if one fire lasts longer than another because of a smaller window, the temperature attained will be lower and this tends to make the severity of the exposure less than the increase in duration would lead one to expect at first sight. If the window openings are large the rate of burning for a given thickness of fuel is proportional to the amount of fuel and the duration tends to become independent of the amount of fuel. The radiation within the enclosure, however, is dependent on the burning rate of the fuel. Thus in both regimes the fire-resistance required of a structure must be assessed in a way rather different from that assumed in present regulations.

Venting of Fires in Large Single-Storey Buildings

Several fires in large undivided buildings in the United States and in the United Kingdom have raised interest in the practicability of venting the roofs of such buildings when fire breaks out. In the study of roof venting it is generally possible to make a model of the air flow provided it is turbulent. The induced velocity of the air u is proportional to $[\theta L/(T_A + \theta)]^{\frac{1}{2}}$ where θ is the temperature above ambient in the enclosure, T_A the absolute ambient temperature and L the linear scale of the model.

There is also a relationship between velocity, temperature and heat production Q which, neglecting heat loss to the walls, may be represented as:

$$u\,\theta\,L^2 \propto Q$$

so that to obtain equal temperatures Q must vary as $L^{5/2}$. Experiments on this basis are being made by the Joint Fire Research Organization.

In the special case of a fully-developed fire it is possible to calculate the vent and curtain sizes required to ensure that all low level openings in the buildings are inlets for cold air. YOKOI[2] and DIAKOV[3] have published methods of calculating these conditions. In the case of a small fire vented at an early stage in its growth it is possible to use the theory of plumes to arrive at the quantities and temperature of hot gases reaching the ceiling.

In addition to the flow problem one must take into account the effect of the changed ventilation conditions on the rate of heat production and a relationship of the kind shown in *Figure 4* of Part I may be used.

Allowance would have to be made for the different geometry of the openings because the air flow is a function of inlet and outlet areas in a way which cannot be described by the one parameter $A\sqrt{H}$. Because of the very different pattern of air flow in relation to fire load there may be different constants of proportionality between air flow and burning rate at low air flow rates. Provided a localized fire is small enough not to be starved in any way, venting would not have a significant effect on the rate of burning.

* In the report referred to by reference 1 the term fire load is defined as the amount of combustible material per unit area expressed in heat units. It is desirable to have a term for the total quantity of fuel or its calorific value and in this paper the term fire load is used for this total quantity and fire load per unit area for the other term.

The effect of venting on the rate of spread of flame over combustible surfaces is also of great importance and work on this aspect of the problem is now being started.

Discussion of Relationship Between Burning Rate and Air Flow

Whilst not a constant, the amount of air required to burn unit mass of fuel must fall within certain limits if combustion is to take place at all, so that over a large range of fuel burning rates one would expect that the burning rate and air flow would increase almost, if not exactly, in proportion. For a fire in an enclosure some of the burning takes place within the enclosure itself, utilizing air that enters the window and other openings while the remainder of the burning takes place outside the windows in flames which entrain additional air.

The fact that the burning rate and the air entering enclosures with small windows are found experimentally to be almost in direct proportion, therefore calls for some further discussion. In general terms, the more air entering the enclosure, the higher the heat release within the enclosure and therefore the higher is the mean temperature of the gases and the higher the heat transfer to the fuel. One would therefore expect the gross burning rate to rise with increased air flow.

A heat balance is not sufficient to predict both the temperature and the rate of burning for a range of fuel and air flow conditions since this can only predict temperatures once the rate of burning is

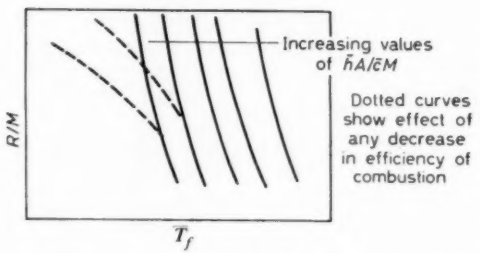

Figure 1. Diagrammatic sketch of heat balance (α curves)

known. Similarly, FUJITA's formula[4] for burning rate contains experimentally determined or assumed quantities, *viz.* the degree of incomplete combustion and the excess air factor. A theory should be able to predict these quantities and, moreover, be able to predict when flaming combustion prevails as opposed to destructive distillation, a process which does occur when the air flow is very small and which may culminate in either self extinction or flash-over. The theory should of course be able to predict the relationship between burning rate and air flow over the whole range of air flow conditions.

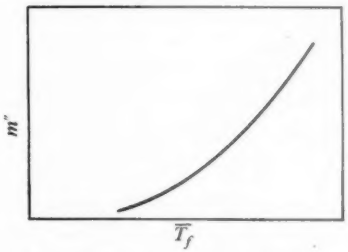

Figure 2. Diagrammatic sketch of decomposition rate as function of temperature (β curves)

To derive such a theory one must discuss in addition to a heat balance

(*1*) The factors (mainly temperature) affecting the decomposition rate of the fuel.

(*2*) The chemical kinetics of the reaction. A simplified equation such as is often used in engineering combustion problems may probably be employed for these.

(*3*) The mixing pattern of the gaseous flow so that the effect of changes in the position of the reaction zone on the heat transfer to the fuel can be discussed.

At present insufficient quantitative data are available to discuss these questions in the necessary detail and what follows must be regarded as somewhat speculative. However in discussing, even in general terms, the construction of a theory it may be possible to focus attention on weak and strong points and thereby more profitably direct future efforts.

The heat balance is considered first. In view of the complexity of the processes and the diverse nature of the heat losses—loss by radiation from the window, loss of heat by hot gases through the window, loss due to the heating of the interior of the wood and the walls—considerable approximations will have to be introduced and the heat balance written in a simple general form assuming that the fuel is in excess so that the flow of oxygen governs the heat output. For any fire where flames emerge from the openings this is a satisfactory assumption. Also for the purpose of this explanation it can be assumed that a mean temperature $\bar{T}_f$ and a mean heat transfer coefficient $\bar{h}$ can be defined for the enclosure so that:

$$[(R + M)\bar{c} + \bar{h}A_w](\bar{T}_f - T_0) = 0{\cdot}23\ M\ Q_0 \quad \ldots (1)$$

where R is the rate of loss in weight of fuel, M the rate of air flow, $\bar{c}$ the mean specific heat of hot gases leaving the enclosure, T_0 the ambient temperature, Q_0 the heat produced per unit mass of oxygen, $\bar{h}$ the mean heat transfer coefficient from the flames to the interior of the fuel and to outside the enclosure through the walls and A_w is the effective surface area of walls, ceiling and fuel.

Equation 1 can now be drawn as curves in *Figure 1* for various values of $\bar{h}A_w/\bar{c}M$ and a fixed value of Q_0. For $R \ll M$, these curves approximate to straight lines. Because $\bar{h}$ depends on the thermal capacity of the walls it changes with time, becoming gradually less. The value of M for fires with small windows is determined mainly by the geometry of the window. For high temperatures it is insensitive to changes in temperature.

The effect of heat on the decomposition rate of wood may be represented by:

$$R = A_f m'' \qquad \ldots .(2)$$

where m'' is the mass rate of decomposition per unit area of wood and A_f is the effective surface area of wood.

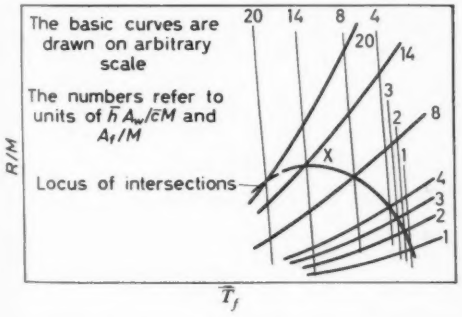

Figure 3. Determination of R and $\bar{T}_f$ (diagrammatic)

It is assumed that the formation of volatiles from the solid material is thermally determined[5], the reactions occurring in the gaseous phase being determined by the gaseous composition within the enclosure; m'' is therefore assumed to be a function of the heat transfer rate at a particular time and, for a given mean heat transfer coefficient, it will depend on the temperature $\bar{T}_f$ in the way shown in *Figure 2*. At high temperatures this curve might be expected to approximate to the fourth power radiation law; m'' is of course dependent on time so the curve in *Figure 2* is also dependent on the temperature-time history of the fire. However, for a given time of heating the curve in *Figure 2* will typify the relationship between m'' and $\bar{T}_f$.

The two relationships in *Equations 1* and *2* are superimposed in *Figure 3* where the decomposition ordinate is proportional to A_f/M. Thus for any one value of $\bar{h}A_w/\bar{c}M$ there is a heat balance curve α and a decomposition curve β.

The intersection X defines both $\bar{T}_f$ and R/M for given values of A_w, A_f and M and in principle is the solution of the problem.

For large values of M, the ordinates of β are small and $\bar{h}A_w/\bar{c}M$ is small so the value of R/M at the intersection X is approximately proportional to A_f/M and R depends directly on A_f. This is the direct relationship between rate of burning and surface area of the fuel observed for large ventilation, which is not dependent on the air flow, and the heat transfer to the fuel is presumably the controlling factor.

As M decreases, the value of $\bar{h}A_w/\bar{c}M$ increases, *i.e.* wall loss becomes relatively more important in relation to the rate of heat production. The α curve moves to the left, and the β curve moves upwards so that the equilibrium position moves upwards and towards the left in *Figure 3*, *i.e.* towards lower temperatures. This is in accordance with the trend shown in *Figure 7* of Part I for temperatures to decrease with a decrease in the amount of ventilation. The locus of the equilibria X is thus of the form shown in *Figure 3*.

The extent of the flattening of the curve would be determined by quantitative relationships between the various factors concerned but clearly the ratio R/M can only become relatively constant if there is a relatively large heat loss to the walls. It is of interest here that in the calculations of the heat loss for the one fire for which he has reported details, SEKINE[6] found a 50 per cent loss.

There are minimum temperature conditions and oxygen/fuel concentrations at which flames can persist and there is therefore a minimum value of air flow for flaming. To discuss air flows lower than this value requires the consideration of chemical kinetics because at very low air flows an equilibrium can be established in which a process of destructive distillation allows the fuel to be consumed at a very low rate and at a relatively low temperature. Any reduction in the efficiency of combustion decreases Q_0. This would tend to reduce the temperature for given values of R, M and $\bar{h}A_w$ (see *Equation 1*) and so flatten the heat balance curves and make R/M even less variable with changes in air flow (see *Figure 1*).

It has now been shown how the ratio of heat loss to the wall to heat generated increases as the air flow decreases and how consequently the ratio R/M, at first inversely proportional to M so that R itself is independent of M, gradually becomes less dependent on M in accordance with the observed behaviour.

From the above arguments, increasing the fire load at fixed values of M and A_w would raise the β curve without affecting the α curve. The rate of burning would thus increase almost proportionally even at low air flows because the heat balance curves are only slightly inclined to the vertical unless combustion becomes increasingly inefficient at lower temperatures. The experimental data[7,8] already referred to, however, do not in general show the burning rate to depend on fire load, though there is some evidence in SIMMS, HIRD and WRAIGHT'S experiments[7] that an increase in surface area produced some, though not a proportional, increase in burning rate (see February *Research*, p. 75). There is thus in general an apparent discrepancy between the experimental data and the simplified theory given above, but there are some possible reasons for this as follows:

(*1*) In both Simms, Hird and Wraight's and Kawagoe's experiments the density of packing for the various elements (sticks, planks, *etc.*) might have been too high for the effective exposed surface area of fuel to increase much with the increases in the amount of fuel. There is doubt therefore if the experiments covered a large enough range of fuel surface area at any one level of ventilation to be conclusive.

(*2*) A_w, the area determining the heat loss will, to some extent, increase with an increase in the surface area of fuel A_f inasmuch as some heat is lost from the gaseous phase to the solid fuel.

Increasing the fire load surface therefore tends to increase the term $\bar{h}A_w/\bar{c}M$. It has already been shown that the effect of increasing $\bar{h}A_w/\bar{c}M$ tends to offset the increase in R/M due to increasing the ordinate of the β curve.

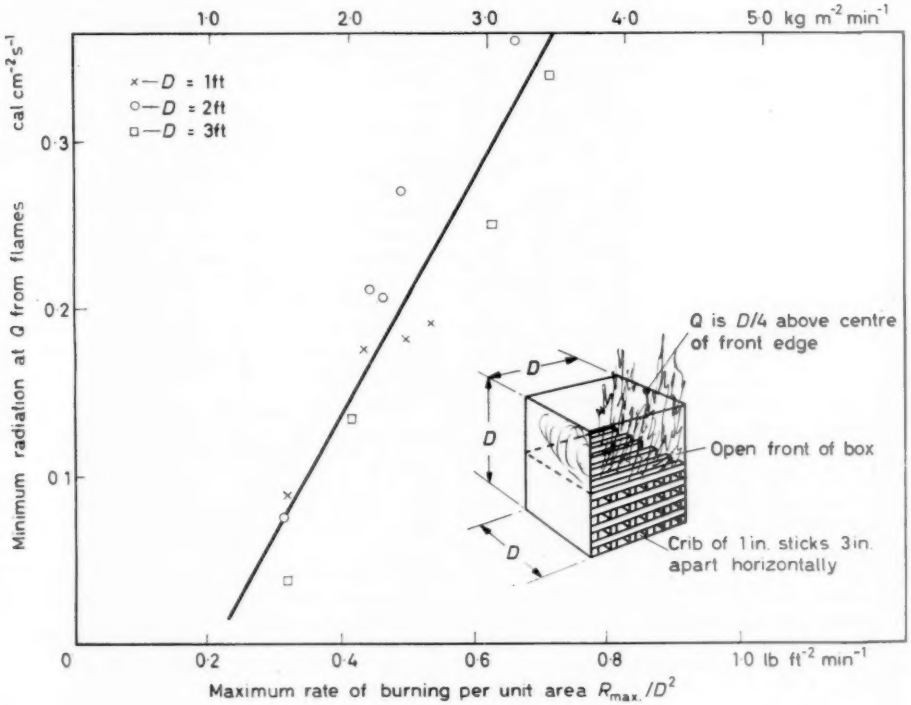

Figure 4. Flame radiation

(3) Any inefficient combustion, as already mentioned, would tend to flatten the heat balance curve and restrict the upward movement of the equilibrium position X, *i.e.* would tend to make R/M less variable for different values of A_f.

(4) The pattern of flow depends on the ratio of forced to free convection flow, *i.e.* on the ratio R/M. Increasing R/M would tend to move the reaction zone away from the fuel surface towards the window thereby reducing the total heat transfer to the fuel and lowering m'' for a given value of $\overline{T}_f$. This tends to counteract the effect of increasing the total surface area of fuel A_f.

Clearly, in view of the above discussion, more information is required on the effect of heat on the decomposition of wood at high temperatures, and further experiments in which the effective exposed area of fuel is varied systemmatically, are necessary. Nevertheless the theory outlined above could be used as a basis for discussing the observed features of fires in compartments and provides a basis for a quantitative theory or a correlation in terms of dimensionless variables.

Hazards to Nearby Buildings

Radiation

Studies of the size of flames and the radiation from them and the radiation from the openings in the elevation of burning buildings are very important in assessing the hazard of a fire to a nearby building.

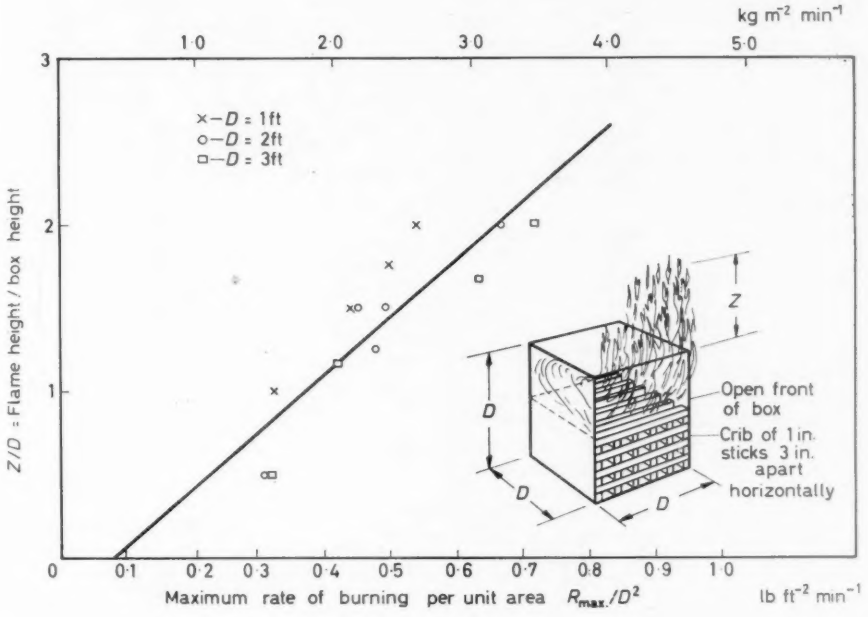

Figure 5. Correlation of flame height for fires in cubes with one open side

The radiation from the opening in a building has been mentioned earlier in connection with the levels of radiation within the cube, but the same intensity of radiation through the window opening can endanger neighbouring buildings if these are too near. In addition to this hazard, the flames themselves radiate heat onto other buildings and also onto the wall above the opening in the burning building itself.

Figure 4 shows the radiation intensity measured close to the flames and for this range of experimental conditions there is a correlation between the radiation intensity and the rates of burning per unit floor (or window) area* for the three sizes of cube.

* Because the data refer only to cubes open on one side one cannot be specific as to floor, or window area.

Because the radiometers were close to the flames, the changes in radiation intensity were mainly due to changes in emissivity, *i.e.* in flame thickness. Although no complete explanation is yet given of the reasons for this correlation one must anticipate its possible breakdown for higher burning rates and large cubes because of the change in the relationship between emissivity and absolute flame thickness; where there are small flames these are proportional, whereas for large flames the emissivity is constant.

Size of flame

In the experiments with wood fires in a cube[9] it was found that with an increase in the amount of fuel and a consequent increase in the total burning rate, the height z of the flames above the top of the opening also increased.

As a first attempt in correlating the results, the ratio of the height z to the cube dimension D was plotted against the burning rate per unit area R/D^2. This is shown in *Figure 5* where it can be seen that there is a slight but systematic trend for the flames from the small cubes to be relatively larger than for the large cubes. In explanation, the turbulent fuel jet discussed by HAWTHORNE, WEDDEL and HOTTEL[10] may first be considered. They showed that the height of such jets is proportional to a linear dimension, namely the orifice size and independent of the fuel flow velocity at the orifice. This was shown to be consistent with the view that air is entrained at a rate M' across the fuel/air interface proportional to the jet velocity and this can be illustrated as follows:

$$M' \propto \varepsilon \times \frac{1}{l} \times \text{area of interface}$$

where M' is the rate of air flow, ϵ is the eddy diffusivity, and l is a characteristic length determining the concentration gradient.

Since for turbulent flow ε may be written as $\varepsilon \propto ul$ where u is the local velocity in the stream, it follows that the flow of air per unit area of interface is proportional to u. This relationship has been used by MORTON, TAYLOR and TURNER[11] in their analysis of buoyant plumes without any other assumption about characteristic length. Now in a fuel jet the momentum at the orifice is large compared with the buoyancy forces, *i.e.* the Froude Number $u_0^2/2g\,z'$, is large compared with l, z' being the total flame height. The velocity at the orifice u_0 therefore determines the velocity u at all points along the jet. In flames from burning fuel this is not always so. The burning rate from these cribs was of the order 1/40 g cm^{-2} s^{-1} so for a gas density of say 2 g/l. at room temperature and say 0·40 g/l. at

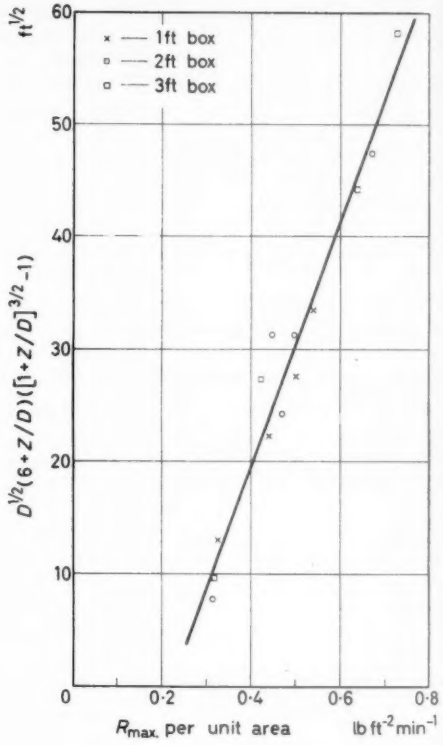

Figure 6. Improved correlation of flame height (same data as in Figure 5)

the flame temperature, the initial velocity is:

$$u_0 \approx \frac{1}{40} \times \frac{1000}{0{\cdot}4} = 60 \text{ cm/s}$$

which for flames of a height of order 1 m gives a Froude Number of $3600/(10^3 \times 10^2) \ll 1$.

The velocity determining the air entrainment is thus the velocity determined by buoyancy and it follows that:

$$M' \propto \sqrt{z'} \times \text{area of fuel/air interface}^*$$

In the case of a fire in an enclosure some combustion occurs within the enclosure and the remainder outside. The surface area of the external flame is equivalent to $2z(D + t)$ provided z is not excessively large compared with D so that the surface may be considered rectilinear.

The mean velocity of the gases in the flame zone outside the enclosure is assumed therefore to be

* This has the same form as the relationship between M and $A_v\sqrt{H}$ for an enclosure at uniform temperature but the constant of proportionality would not be the same.

proportional to the mean value of $\sqrt{x}$ between $D < x < z + D$. Hence

$[(1/z)(z + D)^{3/2} - D^{3/2}]\ [2z(D + t)] \propto M \propto (R - R_0)$

where R is the total rate of burning of fuel, R_0 is the part of fuel burning in the box, and t is the thickness of the flames as they emerge. Since t is small compared with D the following simple correction suffices. For the highest rates of burning when z is of order $2D$ visual observation shows $t \simeq \frac{1}{8} D$ and it is reasonable to take $t \propto R$, *i.e.* approximately $t = z/6$. Therefore

$$D^{\frac{1}{2}}[1 + (z/6D)]\ [1 + z/D)^{3/2} - 1] \propto R/D^2 - R_0/D^2 \quad ....(3)$$

The data in *Figure 5* have been replotted in *Figure 6* in terms of the two sides of *Equation 3* and it can be seen that a straight line is obtained with no apparent systematic scatter. The intercept R_0/D^2 appears to be constant but there is no obvious reason for this. The highest value of the Reynolds number based on the cold gas velocity is of the order 2000 so that part of the flow within the box may be assumed to be laminar.[5] On the other hand the velocities induced by buoyancy are of an order larger than those of the fuel leaving the crib so that turbulence will set in at some point in the box. In view of the extrapolation necessary to obtain R_0/D^2, the error in measuring visually, and the uncertainty about entrainment under the ceiling, it is not possible to explore the variation in R_0 for these results.

The flame lengths of fuel jets were shown by HAWTHORNE, WEDDEL and HOTTEL[10] to depend markedly on the composition of the fuel. For the volatiles emitted from wood this is somewhat uncertain and consequently a quantitative theory has not been discussed here.

Discussion and Conclusion

Although the work on radiation and temperature from fires is incomplete so that it is not yet possible to relate actual fire behaviour to fire-resistance requirements over the whole range of possible circumstances, it has been shown that the present basis of fire-resistance requirements is deficient in some respects.

Experiments on the behaviour of fire in rooms both in the United Kingdom and in Japan have shown that, over a wide range of scale, fires in single compartments with relatively small windows burn at a rate proportional to the total air flow through the window that is induced by the fire.

An outline of a tentative explanation for this behaviour has been given but as has already been pointed out further experimental work is required before this formulation can be regarded as a satisfactory approach. With large windows the air flow is not restricted by the window and the fires burn at a rate which does not depend on window size. The flames from these fires increase in size as the burning rate increases with increased fire load and a qualitative explanation of the observed scale effect has been given in terms of the entrainment of air by turbulence.

So far the main approach to building fires has been experimental and models have at all times had to be justified by comparison with large-scale tests. Even this use of models, limited though it is, has provided information which would have been very much more costly if obtained from full-scale tests alone. It is hoped that future progress will be hastened by the development of an understanding of the basic mechanisms involved in room fires. A start has been made and, though tentative, it explains some of the observed experimental features and justifies one's hopes that modelling can be used as a technique in the examination of building fires.

The work described in this paper forms part of the programme of the Joint Fire Research Organization of the Department of Scientific and Industrial Research and Fire Offices' Committee; the paper is published by permission of the Director of Fire Research. *Crown copyright is reserved on the illustrations.*

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THE PHOSPHONITRILIC DERIVATIVES—AROMATICS WITHOUT CARBON

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This article describes the relevance of some new theoretical ideas to phosphonitrilic derivatives, a series of inorganic polymers with many features in common with organic aromatic compounds. It has been developed from a lecture given to the British Association in September, 1958.

THE subject of inorganic polymers is very topical, due mainly to the great importance attached to the development of materials resistant to high temperatures, and for many applications it is important to obtain materials which will maintain their properties when exposed continuously to temperatures of the order of 400°C. Phenol–formaldehyde and other organic materials begin to break down rather below 250°C. Can inorganic polymers do any better?

In spite of a large amount of work, particularly in this country, in America and in Russia, there is still no certain answer to this question. The silicones are the best-known group of polymers with an inorganic backbone; typical compounds include oils, greases and elastomers, all of which are more stable to high temperatures than corresponding carbon compounds, but are still inadequate for some needs. The phosphonitrilics are related to the silicones in that the repeating unit —P=N— has the same number of electrons as —Si—O—, and, like the silicones, they form both cyclic and linear derivatives[1], some of them of a high degree of thermal stability. Although they are among the more promising of the inorganic polymers at present being investigated, they have not so far found the large-scale application of the silicones, partly because most work has been done on the chlorides, which are comparatively readily available, but which in themselves are too chemically reactive for direct use. Recent work, however, has extended the range of phosphonitrilic derivatives considerably, and some new features in their chemistry are of scientific interest, and seem likely to lead to the preparation of substances with improved properties.

Typical Phosphonitrilic Derivatives

The phosphonitrilic chlorides have a long history. The trimer $(PNCl_2)_3$ was discovered by LIEBIG[2]; its formula was the subject of a controversy between LAURENT on one side and GLADSTONE and HOLMES[3] on the other. Some of the best work was done by STOKES at the turn of the century, and sporadic activity since then has culminated in a renewed and more intense interest in the last few years.

All the cyclic polymers may be prepared by the ammonolysis of phosphorus pentachloride, according to the equation

$$PCl_5 + NH_4Cl \longrightarrow PNCl_2 + 4HCl$$

Phosphorus pentachloride is heated with a slight excess of ammonium chloride[4] at 140°C for some hours. The phosphonitrilic chlorides are extracted from the product with petroleum ether, and separated and purified[5] by a combination of fractional distillation and crystallization. The monomer, $PNCl_2$, shown in the equation has not been isolated. The lowest polymer found is the trimer, comprising about 40 per cent of the total; about 15 per cent is tetramer, 15 per cent pentamer, 5 per cent hexamer and about 25 per cent heptamer and above.

These compounds have cyclic structures, as have the phosphonitrilic fluorides[6] $(PNF_2)_n$, where n is an integer from 3 upwards. The phosphonitrilic series is not, however, restricted to the simple cyclic compounds. There are linear chlorides[7] such as $Cl(PNCl_2)_nPCl_4$ and phenyls[8] such as $Ph(Ph_2PN)_3H$, and at least one compound[5] $P_6N_7Cl_9$ which probably has a condensed ring structure[9] reminiscent of cyameluric chloride. All these molecules are built from P—N units; many other substituent groups besides chlorine, fluoride and phenyl may be attached to the phosphorus without loss of stability. Some typical phosphonitrilic derivatives are shown in *Figure 1*.

This paper is principally concerned with the cyclic phosphonitrilics, particularly the chlorides $(PNCl_2)_n$, because the mutual relevance of theory and experiment is clearest in this case.

Chemical Properties

Before dealing with the theoretical aspects, however, it will be appropriate to deal, first with the general chemistry of the phosphonitrilics, and then with their detailed structures.

Their chemistry will be discussed with particular reference to the trimeric chloride, about which most is known, but the reactions, some of which are shown in *Figure 2*, are typical of the other members of the series as far as they have been investigated. They can be hydrolysed to the acids[10] or esterified[11] with alkoxides. They also react with primary and secondary amines, piperidine[12] for instance. They can be phenylated with phenyl magnesium bromide[8] and undergo the Friedel and Crafts reaction[8] with benzene and aluminium chloride; only two chlorine atoms are replaced by phenyl in this case. The fluorides may be prepared from the chlorides by treatment with potassium fluorosulphite.

$$(PNCl_2)_3 + 6KSO_2F \longrightarrow (PNF_2)_3 + 6KCl + 6SO_2$$

This reaction was discovered[13] only recently; older methods, using lead fluoride[14] for instance, gave mixed chlorofluorides. The trimeric chloride

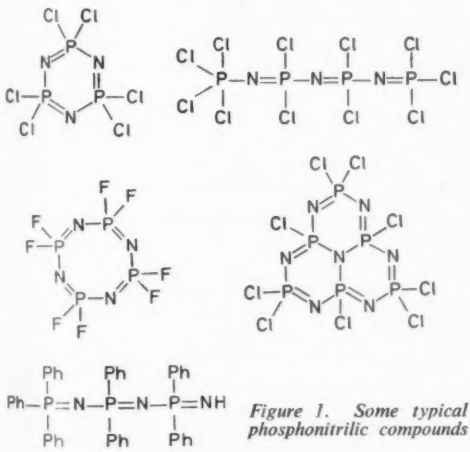


Figure 1. Some typical phosphonitrilic compounds

polymerizes on heating for a long time at 350°C to a solid with elastic properties very similar[15] to those of lightly-vulcanized rubber. In general, similar reactions occur with the tetrameric chloride $(PNCl_2)_4$, which has an eight-membered ring, and some of them with the pentamer and hexamer too. Further details will be found in the general reviews[1].

There are three points of interest in connection with the chemical properties. The first is that although the phosphonitrilic halides undergo many reactions expected of phosphorus–halogen compounds, reaction is often slow. For instance, although it is an acid chloride, the trimeric chloride can be purified by steam distillation. This behaviour may be contrasted with that of, for instance, the phosphorus pentachloride from which it is prepared, which reacts instantly and violently with water.

The second point is that although reaction often requires extreme conditions, the ring structure is usually retained. Thirdly, the chemical inertness is accompanied by a high thermal stability. All the cyclic phosphonitrilic chlorides can be maintained for long periods at 250°C without change; the high polymer requires a temperature of about 500°C for rapid decomposition.

It is not surprising, therefore, that in the search for materials resistant to high temperatures, considerable attention should have been paid to phosphonitrilic compounds. They are scientifically important because their chemical, thermal and structural properties show evidence of aromatic character, not only in the six-membered ring, but throughout an extensive homologous series. The aromaticity is of a new type, involving *d*-orbitals, and shows features which do not occur with benzene and its homologues. These features will become clearer when the structures of the cyclic polymers have been described in more detail.

Structure of Trimeric Compounds

The structure of the trimeric chloride has been examined in various ways. The results of crystal structure determinations[16] confirm and extend earlier electron diffraction work[17] on the vapour; the P—N bonds are equal and short, and the small deviation of the ring from planarity is probably to be ascribed to Van der Waals' forces in the crystal. The P—N bond lengths are much shorter (1·60Å) than the 1·78Å determined for a single P—N bond[18] in sodium phosphoramidate. The stiffness of the bonds can be measured spectroscopically and shows up as a characteristically high frequency in the infra-red absorption spectrum. The P—N stretching frequency is increased from 750 cm^{-1} (single bond)[19] to 1220 cm^{-1} (trimeric chloride)[20], and the bond energy term[21] from 68 to 75 kcal. The trimeric bromide[22] and fluoride[6] have similar structures, which are so far unknown in detail.

The C—C bond in benzene shows similar effects in comparison with that in *cyclo*hexane; it is shorter, stiffer and more difficult to break. It seems reasonable, therefore, to write the structure of the trimeric phosphonitrilic compounds as a resonance hybrid of two Kekulé-type structures (*Figure 3*).

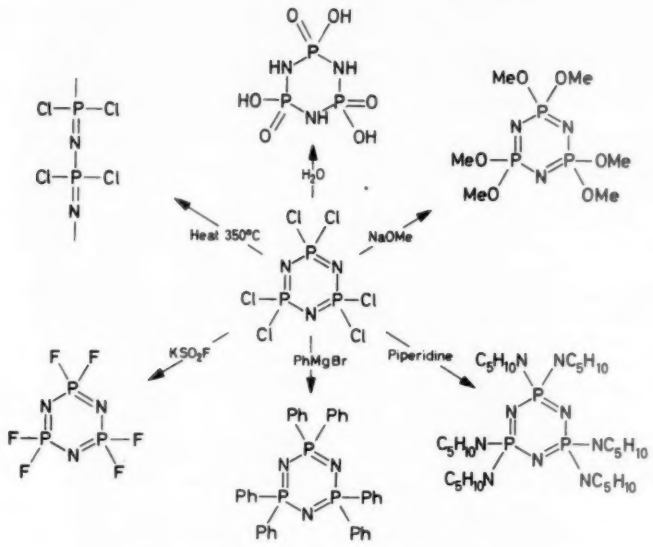


Figure 2. Reactions of triphosphonitrilic chloride

Figure 3. Possible resonance between two Kekulé forms of triphosphonitrilic chloride

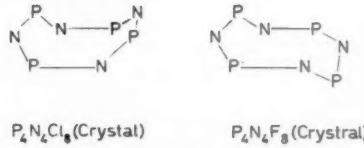


Figure 4. The ring structures of the tetrameric chloride and fluoride

There is no reason to prefer one structure to the other, which is symmetrically related to it. An examination of the structure of the tetrameric compounds shows that some other factors are involved.

Structure of Tetrameric Compounds

The tetrameric compounds also show evidence of aromatic character. The chloride, for instance, is hydrolysed only slowly by water, and is comparatively inert to Grignard reagents, although by the use of forcing conditions it is possible to make the completely phenylated[23] derivative $(PNPh_2)_4$. (This compound can also be prepared in other ways[24]). The P—N bond lengths[25] in the chloride are again all equal, and are short (1·67Å); it seems likely that the difference from the corresponding value for the trimeric chloride will be removed by a more refined analysis. The P—N stretching frequency is again high[20] (1305 cm^{-1}) and indicates a strong bond, though, because of strong coupling between vibrations, not necessarily stronger than in the trimer. The crystal structure determination shows a significant difference from the trimer in that the ring is not flat but puckered. It may be regarded as boat-shaped, the bow and stern being formed from two atoms, rather than one as in *cyclo*hexane. The ring structure of the tetrameric fluoride[26] is different; it has the corresponding chair form (*Figure 4*). The fully phenylated derivative $(PNPh_2)_4$ exists in two forms[23], which may be related to each other in the same way as the chloride and fluoride. The infra-red and Raman spectra show another feature; while the chloride molecule is puckered in the crystal, it is probably flat[20] in solution. There are, therefore, at least three configurations of the eight-membered ring of approximately equal stability.

All the chemical and structural facts, taken together, show two things; first, that the aromatic character observed in the trimer is found also in the eight-membered rings, and second, that it is associated with considerable flexibility.

Comparison with Organic Aromatics

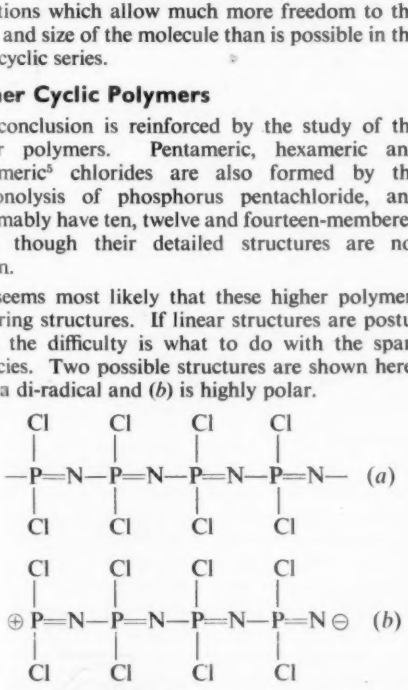
In both these respects the phosphonitrilics differ sharply from the organic aromatic series. A comparison of the tetrameric ring with that of *cyclo*-octatetraene (*Figure 5*) shows that although the two structures are formally similar, there are important differences. The phosphonitrilic has equal and short bond lengths, is comparatively inert chemically, and has sufficient flexibility to assume the planar form in solution; *cyclo*octatetraene, on the other hand, has a similar ring structure, but has alternating single and full double bonds. It is highly reactive, and in contrast to benzene behaves as a typical unsaturated compound. It is also rigid; the definitive structure was determined by electron diffraction[27] in the vapour state.

Not only, therefore, do the phosphonitrilics exhibit aromatic character, but they do so under conditions which allow much more freedom to the shape and size of the molecule than is possible in the carbocyclic series.

Higher Cyclic Polymers

This conclusion is reinforced by the study of the higher polymers. Pentameric, hexameric and heptameric[5] chlorides are also formed by the ammonolysis of phosphorus pentachloride, and presumably have ten, twelve and fourteen-membered rings, though their detailed structures are not known.

It seems most likely that these higher polymers have ring structures. If linear structures are postulated, the difficulty is what to do with the spare valencies. Two possible structures are shown here; (*a*) is a di-radical and (*b*) is highly polar.



There is no sign of behaviour as a radical; the higher polymers are almost as stable to polymerization as the trimer and tetramer. Nor have they marked polar properties. They are soluble in non-polar media such as petroleum ether, and have only small dipole[9] moments. Their infra-red spectra show the expected high P—N bond order, and they are chemically stable; hydrolysis occurs only slowly.

The so far unresolved mixture corresponding to the decamer in average molecular weight has similar properties. The continuity of so many properties with those of the trimer and tetramer is in fact the strongest reason for believing these larger molecules to be cyclic, too. The fluoride series appears to be

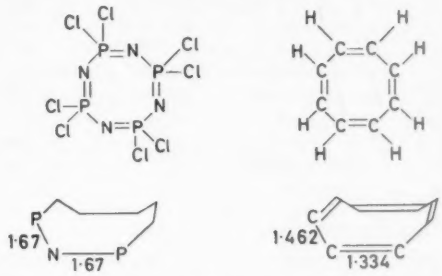


Figure 5. The comparative structures of tetraphosphonitrilic chloride and cyclo*octatetraene*

equally extensive; there is good evidence from vapour-phase chromatography for the existence of phosphonitrilic fluorides up to $(PNF_2)_{17}$, with a thirty-four membered ring[6].

The number of phosphonitrilic derivatives which have been characterized with certainty is now quite large. The trimeric series includes the fluorides[13] $P_3N_3F_6$, the chlorofluorides[28] $P_3N_3F_4Cl_2$ and $P_3N_3F_2Cl_4$, the chloride $P_3N_3Cl_6$, the chlorobromides[29] $P_3N_3Cl_5Br$, $P_3N_3Cl_4Br_2$ and $P_3N_3Cl_2Br_4$, the bromide[30] $P_3N_3Br_6$, the azide[31] $P_3N_3(N_3)_6$, the methoxide[11] $P_3N_3(OMe)_6$, the methyl[32] derivative $P_3N_3Me_6$ and the phenyl derivative[8,24] $P_3N_3Ph_6$. More recent work includes the preparation of the hydrazide[33] $P_3N_3(NH.NH_2)_6$, the *iso*thiocyanate[34] $P_3N_3(NCS)_6$, the amide[35] $P_3N_3(NH_2)_6$, and the chloride–diethylamides[36] $P_3N_3(NEt_2)_3Cl_3$ and[37] $P_3N_3Cl_4(NEt_2)_2$. There are many other examples of partial substitution[38]. The tetrameric series includes the fluoride[13] $P_4N_4F_8$, the chlorofluorides[14] $P_4N_4F_4Cl_4$ and $P_4N_4F_6Cl_2$, the chloride $P_4N_4Cl_8$, the bromide[30] $P_4N_4Br_8$, the octamethyl derivative[32] $P_4N_4Me_8$, the octaphenyl derivative $P_4N_4Ph_8$ and four tetraphenyl derivatives $P_4N_4Ph_4Cl_4$, two of which are probably position isomers[23], and the other two, from the method of preparation[39], stereoisomers. The tetrameric amide[35], methoxide[40] and *iso*thiocyanate[41] have also been prepared. Many more examples could be quoted; several higher fluorides and chlorides are known[1], but their partial substitution products have not been properly characterized. It will be seen, however, that although the discussion of the properties has centred on the chlorides, examples could easily be drawn from a wider field.

Summary of Experimental Evidence

It is convenient to summarize the experimental evidence at this point. All the phosphonitrilics are built up from divalent P—N units, each phosphorus atom carrying two substituents, usually electronegative atoms. Crystallographic, spectroscopic and thermochemical methods combine to show that these PNX_2 units are built up into flexible frameworks of equal, short and strong bonds. There may be as many as thirty-four members in the ring, or possibly more. These cyclic compounds exhibit a thermal and chemical stability of a high order, and all the facts taken together are strongly suggestive of aromatic character. How does it arise, and how does it differ from that displayed by carbocyclic compounds?

Aromatic Character

In benzene the situation is clear. Of the four valency electrons belonging to each carbon three form bonds with their neighbours, two carbon atoms and one hydrogen atom. One unpaired electron remains on each carbon, occupying a *p*-orbital perpendicular to the plane of the ring. These can overlap, so forming a molecular orbital of π-symmetry, that is, with a node in the plane of the molecule. Such a molecular orbital (like any other) will accommodate two electrons.

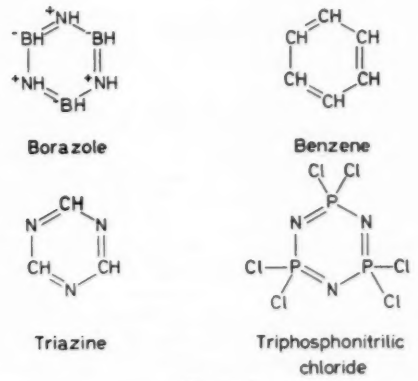


Figure 6

By forming linear combinations of the *p*-orbitals we can construct six independent molecular orbitals. In that of lowest energy, each of the *p*-orbitals is of the same sign and participates equally. It has circular[1] symmetry, its two electrons completing the lowest shell. The next highest energy state is degenerate; there are two molecular orbitals corresponding to it, each with a plane of symmetry perpendicular to the ring and to each other. Each of these orbitals, of identical energy, can accommodate two electrons. The two filled orbitals together have full circular symmetry, thus completing a second closed shell. The first two shells are thus complete with six electrons, just the number provided by the benzene molecule.

The special stability arises from two causes; first, the delocalization of electrons—the greater the volume available, the smaller their kinetic energy. Secondly, the property of shell closure, giving stability just as the rare gases like neon and argon are stable, because their *p*-shells are completely filled. Each successive shell in a p_π-electron set is formed from two-fold degenerate orbitals, so that four electrons are required for each successive shell above the lowest. If only two electrons are provided, as in *cyclo*octatetraene, a half-filled shell results, and no special stability.

The idea of aromaticity in inorganic chemistry is, of course, not new; borazole (*Figure 6*) has been known for a long time as ' inorganic benzene '. In borazole $B_3N_3H_6$ and in triazine $C_3N_3H_3$ for instance, the π-system is composed of *p*-orbitals and the scheme of energy levels is similar to that described for benzene. For the formally similar triphosphonitrilic ring this is impossible. The situation here is analogous, but significantly different, in a way first clearly recognized and adequately treated by D. P. CRAIG[42]. There is a *p*-orbital available on each nitrogen atom, just as there is on each of the nitrogen atoms in triazine and pyridine. All the *p*-orbitals on the phosphorus atom, however, are used in forming four bonds. The fifth electron may, to a first approximation, be regarded as occupying a 3*d*-orbital, which is different in shape and has different symmetry from a *p*-orbital. These two factors are of crucial importance to the phosphonitrilic halides.

The formation of π-orbitals from *p* and from mixed *p-d* orbitals is shown in *Figure 7*. The first scheme corresponds to benzene and related compounds, the second to the phosphonitrilics. The point to notice is that the *p*-orbital changes sign on inversion through its centre, whereas the *d*-orbital does not. For maximum overlap, and therefore maximum binding, successive orbitals of the same type must alternate in sign, so that the true repeating unit is P_2N_2, as can be seen in *Figure 7*. In the case of the trimeric chloride, there is inevitably at least one mismatch of sign, so that complete delocalization in the way described for benzene is impossible. As a result of the symmetry, the energy levels of the trimeric phosphonitrilics are reversed with respect to those of benzene. The highest filled orbital of benzene is degenerate, requiring four electrons; that in the phosphonitrilic is nondegenerate,

requiring only two electrons for closure (*Figure 8*). This feature is general; the highest filled orbital of a *p-d* π-system is always nondegenerate, under the reasonable assumption that the *p* and *d* orbitals are

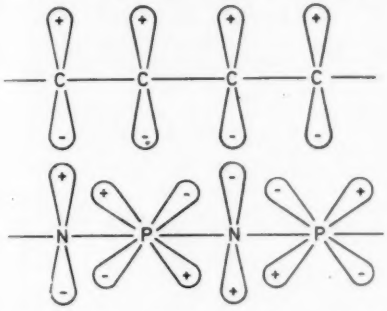


Figure 7. The formation of π-orbitals from p-orbitals and mixed p-d orbitals

of different electronegativity, so that any even number of electrons completes a shell. This is in contrast to π-systems constructed wholly of *p*-electrons, which form closed shells only for $4n+2$ electrons; benzene is aromatic, *cyclo*octatetraene is not, because four electrons are required for shell closure, and only two are provided.

Tetrameric phosphonitrilic compounds, however, are formed from two P_2N_2 units; complete matching is possible all round the ring, and since the outermost shell is filled, a stability greater than that of trimeric compounds is to be expected. The theory shows, in fact, that a steady increase in stability is to be expected as the series is ascended, in contrast to the carbocyclic series, in which π-electron energies alternate as the ring size is increased.

Flexibility

There is another feature worth notice. The 3*d*-orbital of an isolated phosphorus atom is too large and diffuse to overlap effectively with a 2*p*-orbital. It becomes compact enough to do so only with the attachment to the central atom of sufficiently electronegative substituents[43]. Even with two nitrogen and two fluorine atoms attached to the phosphorus atom, however, the *d*-orbital still has considerable lateral extension, and can overlap adequately with its neighbours even when twisted out of line. Because of this, phosphonitrilics exhibit far more flexibility without loss of aromatic character than is possible in a π-system composed exclusively of *p*-orbitals, which are comparatively restricted in space. The requirement of planarity of the conjugated system is therefore much less strict than in the carbocyclic series. The consequent flexibility, coupled with the filled-shell property, ensures the stability of the higher members of the series, and perhaps accounts for their formation in comparatively high yield in the ammonolysis of phosphorus pentachloride.

Consequences of the Theory

Molecular orbital theory of a simple type can evidently be used to elucidate the main features of the chemistry and physics of phosphonitrilic ring systems. It is interesting to see what happens when we go outside the series of cyclic chlorides, which has been the basis of most of the practical work. The substituents on the phosphorus atom play an important part in determining the stability of the aromatic system. The more electronegative they are, the greater the contraction of the 3*d*-orbital, and the greater the stability of the resulting π-electron system, though the existence of the methyls[32] $P_3N_3Me_6$ and $P_4N_4Me_8$ shows that the electronegativity requirement is less strict than for the participation of *d*-orbitals in localized bonds. Although the π-electrons are responsible for the distinctive characteristics of the phosphonitrilic

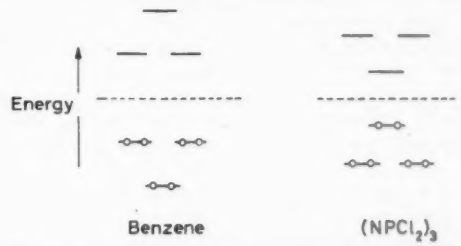


Figure 8. Energy sequences of molecular orbitals. The dotted line divides filled from unfilled orbitals and is placed arbitrarily in the energy scale. (Reproduced by kind permission of Professor D. P. Craig)

series, the binding is chiefly derived from the electrons localized in σ-bonds; the net result is that the phosphonitrilic fluorides, chlorides, bromides and phenyls are comparable in many respects. On the other hand, it is unlikely that the phosphonitrilic hydrides will be much more stable than the hypothetical PH_5, in which the contraction of the *d*-orbitals is insufficient to allow the appropriate type of hybridization.

There are some further consequences of the theory. CRAIG has pointed out that as any even number of electrons constitute a filled shell, the dimer $(PNCl_2)_2$, with a four-membered ring, should be less unstable with respect to the trimer than the unknown *cyclo*butadiene is to benzene; (*cyclo*butadiene would have a half-filled shell). The

dimeric chloride has not so far been isolated, but it may be significant that the tetrameric chlorofluorides dissociate reversibly[14] on heating, as shown in the following equations

$$P_4N_4Cl_2F_6 \rightleftharpoons 2P_2N_2ClF_3$$
$$P_4N_4Cl_4F_4 \rightleftharpoons 2P_2N_2Cl_2F_2$$

The shape of these dimeric molecules is not known.

At least as important is the application of the idea of *p-d* π-bonding to elements other than phosphorus. In a lecture to the Chemical Society[44], CRAIG has extended the theoretical approach to compounds of sulphur and nitrogen. The situation here is a little more complicated, in that the d_{yz} orbital is involved as well as the d_{xz} orbital, and its use tends to reverse the order of stability of six-membered and eight-membered rings.

Nevertheless, thiazyl chloride $(NSCl)_3$, the thiazyl fluorides $(NSF)_3$ and $(NSF)_4$, sulphanuric chloride $(NSOCl)_3$ and many other compounds[45] fit into the same general scheme as the phosphonitrilics, though their chemical behaviour is more complicated; the chemical implications of the theory are clearest with the phosphonitrilics, because there is only one *d*-electron per phosphorus atom. It is possible here to see an underlying unity in apparently diverse chemical behaviour, and to plan further experimental work on a rational basis.

With regard to high-temperature applications, the effects mentioned seem likely to provide some improvement of thermal stability over materials at present in use. At the same time, however, not all the *d*-orbitals are used in bonding, and the phosphorus atom is in part left open to chemical attack, though this is of course a less important effect than in non-aromatic compounds. The attainment of an adequate chemical stability without impairing the thermal properties is at present an active field of research, and is a problem which must be solved before full advantage can be taken of this newly-recognized form of chemical binding.

The author is pleased to acknowledge stimulating discussions with his colleagues, and the help of Mr F. R. Tromans in preparing the diagrams.

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REACTION ZONE LENGTH AND FAILURE OF DETONATION IN AZIDES

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From measurements of the detonation velocity as a function of the charge diameter reaction zone lengths of 0·2 mm for single lead azide crystals and 0·45 mm for lead azide powder are estimated. A critical thickness of 0·022 mm for failure of detonation in single silver azide crystals is measured. The results seem to be consistent with the surface-burning theory for chemical reaction in detonating explosives, but not with the theory for failure of detonation in charges with decreasing thickness. An explanation for this discrepancy is suggested.

Most work on the effect of charge diameter on the detonation velocity has hitherto been concerned with secondary explosives such as TNT, tetryl *etc.* The only investigation on primary or initiating explosives is that by Bowden and McLaren[1] on lead azide pressed into very thin sheets. The calculated length of the reaction zone from their experiments is *c.* 75 microns whereas the reaction zone length for the most typical secondary explosives is of the order of 1 mm.

This paper describes similar measurements on single crystals of silver and lead azide and on loose unconfined lead azide powder. Experimental results on failure of detonation in very thin single crystals of silver azide will also be presented.

Experimental

Both the silver and the lead azide crystals were needleshaped. The former were fairly regular so that their width and thickness might easily be measured by means of a microscope. The latter were of a most irregular form and a direct measurement of the dimensions was therefore useless. However, an estimate of the cross section was obtained by weighing each crystal, measuring its length and calculating the radius of an equivalent cylindrical rod. A similar method was used for the loose unconfined lead azide powder.

The detonation velocity was determined by means of a rotating drum camera described by Bowden and Gurton[2].

Some crystals of silver azide were so thin that failure of detonation occurred. In order to study this failure crystals with gradually decreasing thickness were selected and the thickness was measured at short intervals along the length. A crystal was then initiated from the thick end by a trail of lead azide powder or directly by a hot wire and the incision produced by the detonation on a sheet of mica was studied. As will be seen from *Figures 1* and *2* the incision caused by the crystal is clearly distinguishable from that caused by the azide powder, and by measuring its length it was possible to estimate the thickness at which the detonation had stopped.

Experiments were also carried out with such crystals directly ignited from the thin end. In other experiments a second crystal (receptor) with thickness above the critical size was placed in direct contact with the thin end of the first crystal (donor) which was then initiated from the opposite end.

In order to make sure that there was a fairly close correspondence between detonation length and incision length similar experiments were also carried out with crystals of greater and constant thickness. It appeared that the incision was always a little longer (about 0·5 mm) than the crystal. This discrepancy was however of minor consequence for the estimation of the critical thickness for failure.

Results

An attempt was made to explain the results in terms of the theories developed by Jones[3] and by Eyring, Powell, Duffey and Parlin[4] for the effect of size on detonation velocity. These theories are valid only for detonation velocities not much lower than the ideal one and great discrepancies were therefore expected. It also appeared that the results do not

fit Jones' theory very well. However, the results for lead azide powder are in fairly good agreement with Eyring's theory. For single crystals of lead azide the deviations from the theoretical curve are greater, probably on account of a greater uncertainty in estimating the equivalent radii.

The results are plotted in *Figure 3* where also the theoretical curve according to Eyring is drawn. For lead azide powder (density 2·0 g/cm³) and lead azide single crystals ideal detonation velocities of respectively 3400 and 5600 m/sec are assumed (ROTH[5]). From these data reaction zone lengths of 450 microns for lead azide powder and of 200 microns for single crystals of lead azide are estimated.

The dimensions of the silver azide crystals were so small and hence the detonation velocity so low (*c.* 1000 m/sec) that it seemed unjustifiable to estimate the reaction zone length from Eyring's theory. The results indicated that the detonation velocity is mainly dependent on the thickness of the crystals whereas their width is of minor importance. There seems to be an approximately linear relationship between the detonation velocity and the thickness of the crystals as shown in *Figure 4*. Some of the silver azide crystals were so thin that stable detonation was impossible.

Experiments on this failure of detonation showed that the critical thickness for failure is *c.* 22 microns. The detonation of such tiny crystals produced no visible trace on the drum camera film. However, a detonation velocity of 6–700 m/sec can be estimated from the approximately linear relationship between detonation velocity and crystal dimensions at greater thickness.

When the crystal was initiated from the thin end, the explosion of the crystal left no visible trace on the mica until the thickness had reached a value of about 25 microns. The effect produced on the mica indicated an abrupt change from slow explosive decomposition to detonation. Finally the experiments with the donor–receptor crystals showed that when detonation in the donor failed, the receptor was not initiated even if its dimensions were adequate.

Discussion

As already mentioned BOWDEN and MCLAREN[1] found a reaction zone length of 75 microns for lead azide (density 3·14 g/cm³) pressed into thin sheets whereas the reaction zone length in the present investigation has been estimated as 200 and 450 microns for single lead azide crystals (density 4·6 g/cm³) and loose lead azide powder (density 2·0 g/cm³) respectively. These discrepancies may be explained by means of the grain burning theory for the reaction mechanism in detonating explosives. According to this theory each grain of explosive begins reacting at its hot surface, and the reaction progresses layer by layer until it reaches the centre of the grain.

Let us first consider the loose azide powder. The chemical reaction in a detonating substance is thought to start at the spots where the highest temperatures occur. These spots are obviously the loadbearing contact points at the surface of each grain of explosive, these points being subject to the greatest compressional and frictional heating upon the impact of the shock wave. The reaction zone length will not be perceptibly influenced by the

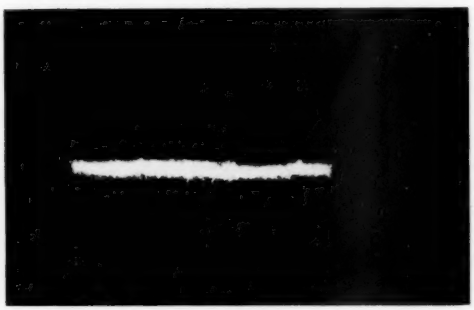

Figure 1. Trail of lead azide powder + silver azide crystal with decreasing thickness (× 4)

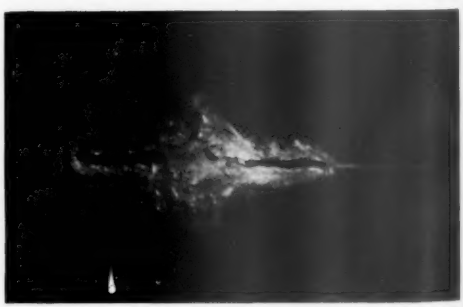

Figure 2. Effect of detonation on sheet of mica (× 4)

density so long as there is a great number of such hot spots present at the surface of each grain. A great reduction of the number of loadbearing points will, however, increase the distance traversed by the

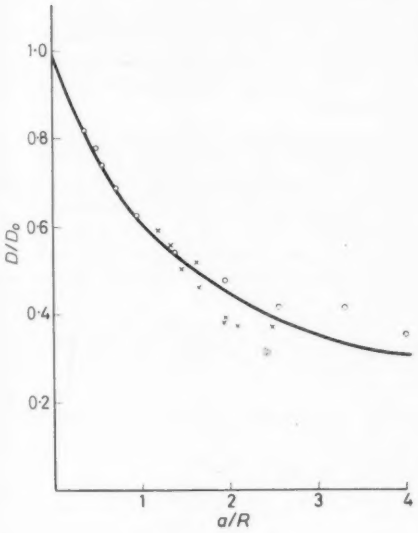

Figure 3. Dependency of detonation velocity (D) on charge radius (R); circles: lead azide powder. Ideal detonation velocity $D_0 = 3400$ m/sec, reaction zone length $a = 450$ microns; crosses: single crystals of lead azide. Ideal detonation velocity $D_0 = 5600$ m/sec, reaction zone length $a = 200$ microns

decomposition and hence the reaction zone length. Following the arguments of EYRING[4] a perceptible lengthening of the reaction zone may be predicted below a density of 3·4 g/cm³ and a marked lengthening below a density of 2·4 g/cm³ for lead azide of crystal density 4·6 g/cm³.

The grain burning theory also accounts for the greater reaction zone length of the single crystals compared with the value of 75 microns for pressed sheets of lead azide. In fact one might expect that in a completely faultless crystal low velocity detonation would be impossible as it seems to be a necessary condition that in some way discontinuities must exist or be introduced within the crystal. Now these crystals of silver azide were by no means crystallographically perfect and it seems reasonable to assume that hot spots are formed at these imperfections which consequently will serve as reaction centres. Another possibility is that the crystal on the arrival of the shock wave is disintegrated into fine particles which will provide a sufficient reacting surface for stable detonation.

The experiments with the tiny silver azide crystals showed that the critical thickness for failure of detonation is 22–25 microns, at which value the estimated detonation velocity is 6–700 m/sec. Though still thinner crystals may be ignited, the propagation is probably a very slow one, distinctly different from a detonation. However, a transition from burning to detonation will occur as soon as the thickness exceeds the critical value. On the other hand in a crystal with decreasing thickness a transition from detonation to burning is impossible. The detonation will in this case propagate with decreasing velocity until it reaches the critical thickness whereupon no further explosive propagation is possible. These results are in good agreement with the observations by EVANS and YOFFE[6] that silver azide crystals of diameter 25 microns still explode whereas crystals of diameter 10 microns burn at a speed of 7 m/sec.

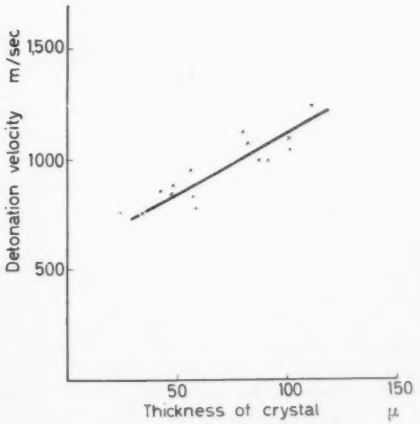

Figure 4. Detonation velocity as a function of the thickness of silver azide crystals

A detonation velocity of 6–700 m/sec is however not consistent with the theory developed by EYRING[4] for failure of detonation in charges with decreasing diameter. According to this theory and assuming a very low heat of activation failure of detonation will occur at a charge radius twice the reaction zone length corresponding to a detonation velocity half the ideal one. Evidence for this theory is provided

by several experiments with secondary explosives. However, it is quite obvious that this theory is inadequate for primary explosives such as the azides, as stable detonation is observed at detonation velocities of *c.* 800 m/sec which is much lower than predicted by the theory.

One of the conditions in the development of Eyring's theory is that the temperature is substantially constant throughout the reaction zone. More recently PATERSON[7] has shown that in granular explosives the temperature in the air pockets at the shock front is very much higher than in the Chapman–Jouguet plane. However, because these air pockets have an extremely small heat capacity the high temperature is a transient phenomenon compared with the reaction time. The assumption of constant temperature will therefore be correct for most of the reaction zone.

If we now assume that very high temperatures will also be encountered in discontinuities at the shock front in a detonating single crystal, it is possible to explain why Eyring's theory is valid for secondary explosives but not for primary explosives such as the azides.

The high temperature in the shock front will start the reaction both in primary and secondary explosives. In a secondary explosive the first steps of the decomposition are endothermic, and it will take a comparatively long time before the heat of reaction is of any significance for the propagation of detonation. In this case it will be permissible to assume an approximately constant temperature throughout the reaction zone. On the other hand primary explosives and especially the azides decompose in very few steps and it is reasonable to suppose that the heat of reaction from the molecules initiated in the shock front is liberated so fast that the temperature in the meantime has insufficient time to fall below the value necessary for initiating new molecules. In this case it would be incorrect to assume a constant temperature throughout the reaction zone and it seems obvious that detonation might propagate with a much lower velocity than possible according to Eyring's theory.

The experimental part of this work was carried out in the Research Laboratory for the Physics and Chemistry of Solids, Department of Physics, University of Cambridge. The author wishes to express his thanks to Dr F. P. Bowden and Dr A. D. Yoffe for their interest and helpful suggestions and to the Royal Norwegian Council for Scientific and Industrial Research for a fellowship. The illustrations are reproduced by kind permission of Tidsskrift for Kjemi, Bergvesen og Metallurgi (1959) **19**, *95.*

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1960 ESSAY COMPETITION FOR SCHOOLS

THE *Research* Essay Competition for Schools was instituted in 1957 with the purpose of encouraging scientifically-minded school pupils to write clearly and comprehensibly about their work; thus it was hoped to assist in raising the standard of the writing of scientific reports in the future.

The 1960 competition has reverted to its original form. Schoolboys and schoolgirls are asked to write a report of 1000 to 1500 words on any recent piece of practical work or special project they have carried out in chemistry, physics or biology. The author of the best report, in the opinion of the judges, will receive a prize of books to the value of £15 and there will be a second prize of books to the value of £10. In addition, books to the value of £15 and £10 will be awarded to the school libraries of the first and second prize winners respectively.

Full details of this competition are available from the publishers of *Research*, 4 and 5 Bell Yard, London, W.C.2.

MINIATURE RELAYS FOR USE IN ELECTRONIC EQUIPMENTS

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The conditions in which guided missiles and space vehicles must operate, and the high degree of reliability required necessitates special attention to miniaturization and methods to combat severe shock and vibration. The relays to be described withstand vibration levels far in excess of present requirements and introduce new types admirably suited to present trends in highly reliable, small volume ground equipment generally.

MODERN service electronic equipment requires extremely reliable, high quality components in order to justify the expenditure of the vast sums of money and years of research and development which must precede the manufacture of any advanced electronic weapon. In particular, high speed aircraft, guided missiles and space vehicles demand equipment reliability far in advance of past and present achievement.

During the quarter century 1920–45 progress in the development of electromagnetic relays in this country was negligible. The second world war raised the problem of better relays, but nothing very original appeared. Since then rapid advance in computing equipment, missiles and the development of the transistor has encouraged the development of more reliable relays, some of which are now comparable in size to switching and power transistors.

Environment

Relays have only one simple and fundamental function to perform—to connect, or disconnect, a circuit at a time indicated by energization of its coil. Severe service environments make it difficult to achieve complete reliability; the many variables associated with the manufacture and assembly of parts, and the testing of the completed relay often prevent this simple function being accomplished.

The deleterious effects of global weather can be eliminated by sealing the relay in a tin box, which also prevents inquisitive fingers tampering with adjustments. However in this case either the contacts should be contained within a separate sealed compartment, constructed of inorganic materials, or some other safeguard should be incorporated to prevent their contamination.

Vibration

Modern missiles vibrate a great deal, and the electronic equipment contained within them must withstand very high levels of G over a wide frequency band. The relays to be described all withstand about 100 g over a range of frequency from 50–2500 cycles. This is achieved by using mass balanced armatures, extremely robust construction, and by miniaturization. Because some engineers believe that there is always some torsional vibration in the electronic equipment chassis of missiles, some of the relays to be described have two armatures linked together in such a way that they are not influenced by torsional or linear vibration.

Miniaturizing a relay has many advantages. Halving linear dimensions reduces the mass of the parts by a factor of eight and doubles the resonant frequency. The reduction in the mass of moving parts and in the time constant of the smaller coils combine to produce faster operating relays. Because magnetic forces and the contact pressures are reduced by a factor of four it is extremely important to design the relay from fundamental principles. Great ingenuity is required, and this, together with the highest class workmanship and a 'surgically' clean assembly area facilitates the production of very reliable relays.

The Relay Contact

The most important part of a relay is the contact. If this remains clean throughout the life of a relay then conduction will always take place from one contact to the other. This, however, is seldom the case. To understand the problem better, the characteristics of clean, slightly oxidized, heavily oxidized, and dirty contacts will be considered.

The ideal contact is metallurgically clean and has zero resistance under any condition. It would be equivalent, by virtue of close atomic adhesion, to a cold weld. In practice it can be taken that when this condition is attained the contact resistance is about a m ohm or less. Most contacts in air quickly become covered with a tenacious film of oxide which usually grows thicker and thicker with the passage of time. If a high enough voltage is applied to such contacts, conduction is brought about by phenomena related to the film and its thickness; this oxidation process can be reduced by sealing relays in a reducing atmosphere.

Gaseous Film

Perhaps the thinnest of films are those formed by the gas or mixture of gas contained within the sealed relay. This layer may be about 3 to 4 Å thick when two contacts come together and would require a field strength of 10^6 to 10^7 V/cm to rupture it; thus a potential drop of about 10–100 mV would produce a metal-to-metal contact. If rupture does not occur in this way conduction takes place as for thin oxide films.

Thin Films

Films up to about 30 Å thick present a resistance less than that indicated by the resistivity of the contaminating material. Conduction is achieved by 'tunnel effect' in accordance with Fowler–Nordheim theory, in which wave mechanical motion analogous to the transmission of light through a very thin metal foil takes place. The effective resistance is independent of the applied voltage and temperature but related to film thickness, and would be in the region of 10 m ohm or less.

Thick Films

Many contacts have a contamination film which is too thick to permit conduction by tunnel effect. These films, possibly several thousand Ångströms in thickness are usually semi-conductors, and conduction through them is due to a high intensity field puncturing the film. Rupture may take place at a fraction of a volt or several hundred volts depending upon film thickness. When breakdown occurs the contacts are bridged by molten metal filaments about 100 Å thick, which solidify as soon as their combined volume is sufficient to carry the load current. The resistance of such a pair of contacts might then be in the region of 50 m ohm.

Dust

High resistance contacts are commonly caused by dirt and dust. A fairly clean room can contain as many as 1000 particles per c.c. A hard particle could cause disconnection, but usually these fine, gossamerlike bodies are crushed and decomposed in the arc and contribute to contamination and high resistance.

Polymers

Some contact materials, in particular those of the platinum group, produce a dark deposit in the contact area after a period of operation, or as the result of vibration or friction. This phenomenon is associated with the presence of organic vapours from insulating materials and wire insulant, and is more prevalent in sealed relays than in unsealed ones. Any contact surface bearing carbonaceous deposits will arc more freely and generally erode more quickly than a clean contact.

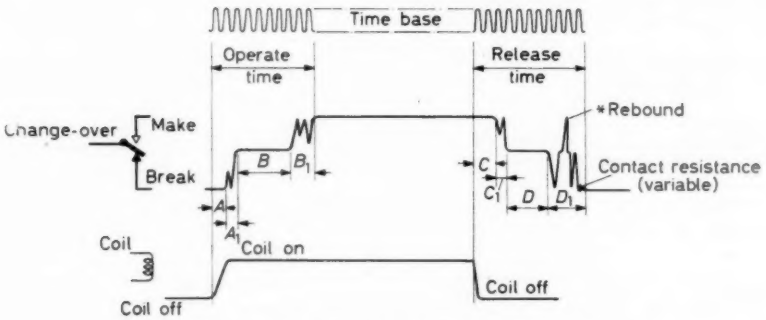


Figure 1. Typical operating characteristics of a relay

Operate time $= A + A_1 + B + B_1$.

A = *Operate of break contact*
A_1 = *Break bounce time*
B = *Transit time (operate)*
B_1 = *Make bounce time*

Release time $= C + C_1 + D + D_1$

C = *Release of make contact*
C_1 = *Bounce of make on release*
D = *Transit time (release)*
D_1 = *Bounce of break on release*

Contact Material

A soft material such as gold has a softening point voltage of 80 mV, and a hard material, such as tungsten, 400 mV. When the material softens, the surface moves under the contact force and the contaminating film is disturbed. The contact resistance, measured at this, or any higher voltage may therefore be erratic.

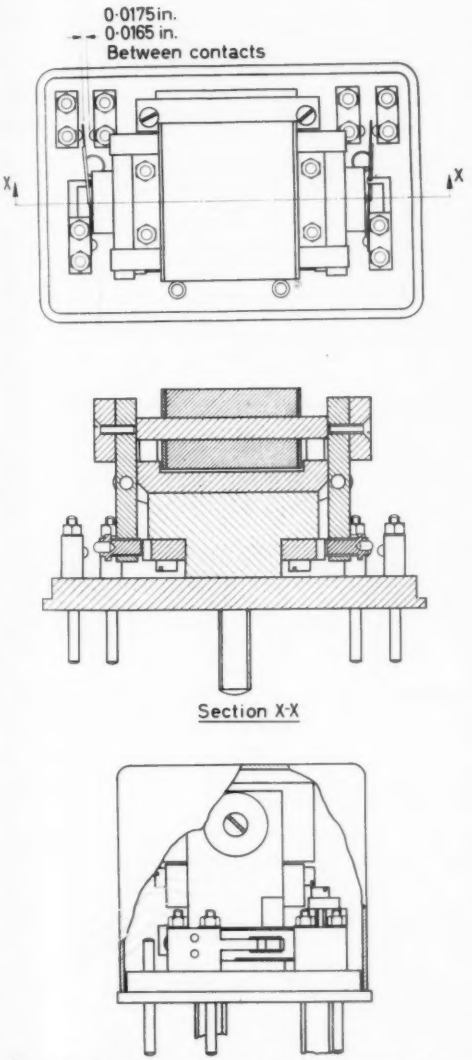


Figure 2. Century G relay with two changeover contacts (Courtesy New Electronic Products Ltd)

Operating Characteristics of a Relay

In order to assess the virtues of a relay it is necessary to consider the precise operating characteristics of a single-changeover contact associated with it. A typical behaviour pattern is shown in *Figure 1*, and definitions are provided for the various stages.

The total operating time of a relay can be seen to consist of the product of the time from switching *on* the coil, to the first movement of the break contact (A), the bounce of the break contact (A_1), the transit time (B), and the bounce of the make contact (B_1)—similarly, the total release time is equal to $C + C_1 + D + D_1$.

The object in design is to eliminate the four bounce periods shown. Those at A_1 and C_1 are usually only present in a badly designed relay with inadequate contact pressure or weak magnetic field and are easily overcome. Rebound is a manifestation of excessive bounce. It is not so easy to overcome bounce at B_1 and D_1. The former is due to the kinetic energy from the armature resulting in impact of the armature on the pole-face and the contacts upon one another, and the latter due to impact of the contact and armature on release of the relay.

The moving contact does not come to rest after the first impact, but bounces owing to the elasticity of the material. The circuit, just made, is then broken and an arc may be drawn. This continues in the form of damped vibration until the contacts settle down and remain stationary. To reduce bounce the weight of the moving object and the kinetic energy behind it should both be small and the contact pressure much greater than the weight of the moving contact, a condition more suited to the design of small relays than large ones.

Century G Relay

For use in missiles and other weapons where a high degree of reliability must be coupled with resistance to high level vibration and shock, a variety of special relays have been developed for R.R.E. by New Electronic Products Ltd of London. These relays incorporate two changeover and four changeover contacts and are available in orthodox form and also with magnetic latching. Tests indicate that they will withstand 100 *g* vibration over a frequency range of 50–2500 c/s.

Both the 2 c/o and the 4 c/o relays measure 1·1 in. × 0·726 in. × 0·7 in. The former has a single header and is shown in *Figure 2*; the latter has two headers, the second being placed opposite the existing one and carrying the second pair of contacts. The magnetic latching relay has two coils and is a little larger.

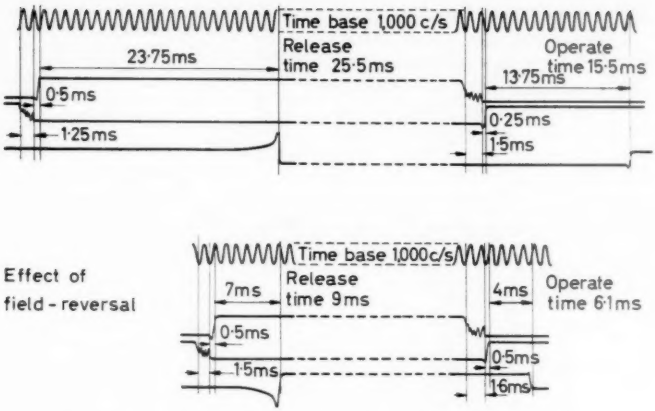


Figure 3. Operate and release characteristics of Century G relay (Courtesy New Electronic Products Ltd)

These relays employ two well-balanced armatures suspended about their centre of gravity by large pinion bearings. Fixed rigidly and at right angles at one end of each armature is a novel linkage system which combats linear and torsional vibration by allowing the armatures to rotate only in opposite directions and at the same instant. The armature movement is 0·005 in. at the pole-face and contact gaps are at least 0·015 in. In the 4 c/o relay, both ends of each armature operate a restrained spring changeover contact assembly, but only one end of each armature operates the contacts of the 2 c/o relay.

Both relays include a permanent magnet to aid return of the armature and to hold it securely in the un-energized condition. The magnet lies parallel to the electro-magnet coil, which presents some interesting and incidental advantages. The differential fields are easily adjusted by slight movement of the magnets, or by fitting various sizes of magnet. This facility, coupled with reversal of the electro-magnet field, changes the operate and release times considerably. The contact operate and release characteristics remain constant and independent of the operate and release speed of the relay. These characteristics are shown in the oscillographic form in *Figure 3*. It can be seen that the operate time has been changed from about 6 ms to 15·5 ms, and the release time from 9 ms to 25·5 ms, by merely changing the polarity of the coil input. The contact characteristics remain very much the same, showing no bounce at positions B_1 and D_1 and a transit time (B and D) of only 0·5 ms maximum.

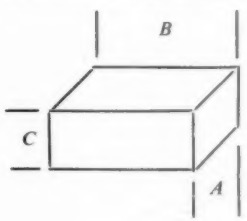
Tests carried out on 4 c/o relays operating on 180 mV gave operate times in the region of 5 to 10 ms and release times of similar dimensions depending upon the polarity of the coil input voltage. The bounce was in the region of 1 ms.

Vibration Test

Some vibration test results are shown in *Table 1*, where it will be seen that the relay has not been

Table 1

Plane	*Acceleration g*	*Freq. c/s*
C	20–60	30–2000
	70–80	600–2000
	90	600–2000
A	20–60	30–2000
	70–80	600–2000
	90	700–2000
	100	900–2000
B	20–60	30–2000
	70	900–2000
	80	600–2000



tested at 100 *g* throughout the complete frequency band. This is due to limitations in vibration test gear. However, most of the frequency band has been covered up to 60 *g* level, and a fair coverage up to 100 *g*. Independent tests for use in special circuitry carried this investigation up to 10 kc/s at an acceleration of 25 *g* without premature 'make' or 'break' of the contacts.

The latching version of this relay has the permanent magnet in line with the axis of the centre of the armatures which remain in the position in which they were last driven. By using two coils the relay can be used as a polarized relay.

Micro-relay

For use in auto-pilot equipment, digital synchro-conversion receivers, computers and the like, an extremely small and reliable relay, comparable in size to a switching transistor, has been designed for R.R.E. by Smiths Aircraft Instruments of Cheltenham. This firm is now in production of this, the world's smallest two-compartment relay. Tests indicate that such small relays are quite capable of operating for 40×10^6 operations without undue wear on the contacts. This relay is cylindrical in shape, measures 0·3 in. diameter and is 0·47 in. long with axially placed leads at each end. It weighs only 2·5 g and is shown in *Figure 4*.

This tiny relay consists of a pot type magnetic circuit with an armature lid suspended on a short flat return spring which permits pivoting of the armature and moving contact to perform the change-over function. The centre-pole and end-cheeks are first turned from soft iron, with an extension at the centre-pole end for handling purposes. A brass coil-sealing disc is brazed on, and the wire terminations and bushes assembled. This sub-assembly is then coated with *Araldite* or moulded to provide a bobbin on which the coil wire is wound. The sealing disc is then soldered to the body and the pole faces ground flush. Gold plated platinum wire contacts, sealed into the header, are formed to the correct gap and, with the armature in position on the header pins, the closed contact is adjusted to give 10–15 g pressure. The gold plate ensures low contact resistance during storage.

Both magnet body and contact assembly are loaded into an alignment jig and the coil energized with the maximum volts. The two halves are pressed together until the relay contacts change over. The coil volts are then reduced to the minimum

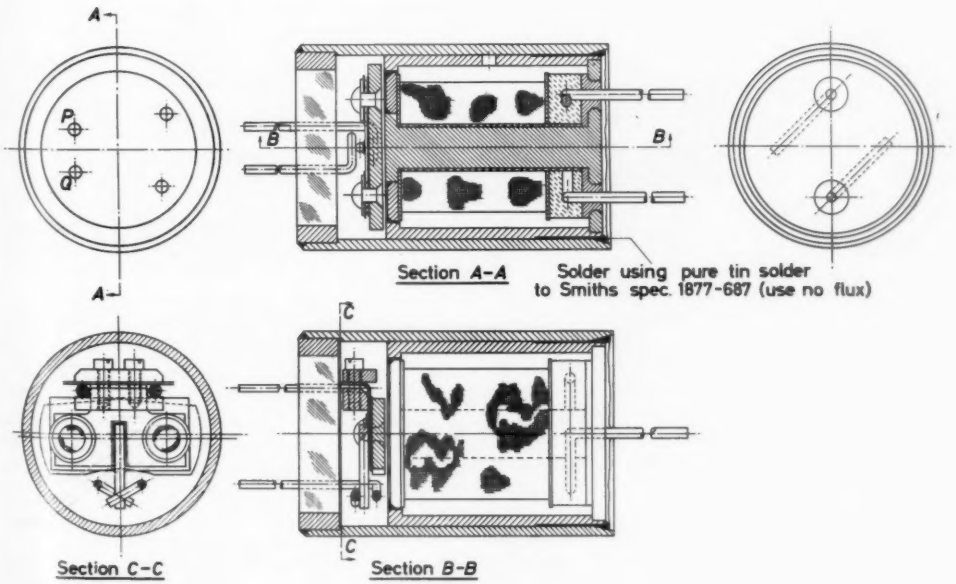


Figure 4. Micro-relay (Courtesy Smiths Aircraft Instruments)

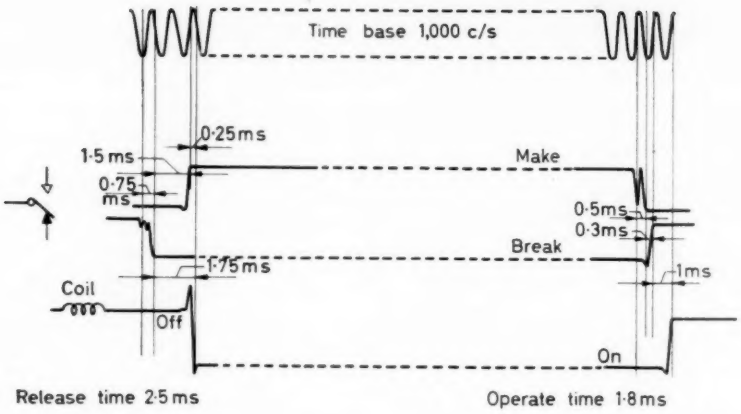


Figure 5. Static operating characteristics of micro-relay operated on nominal voltage. (Courtesy Smiths Aircraft Instruments)

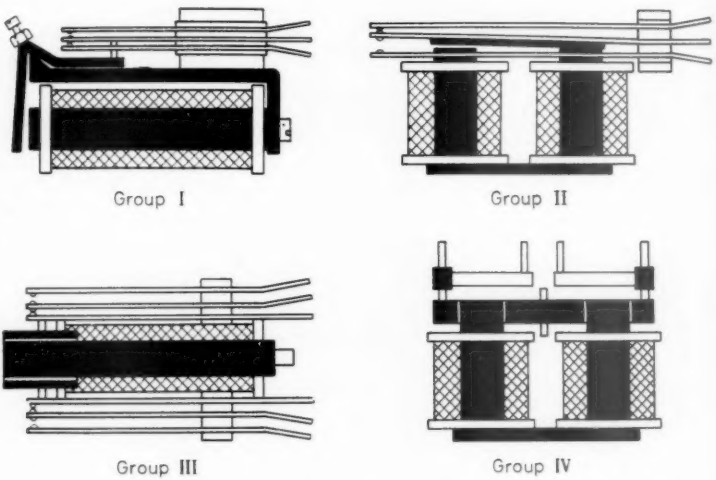


Figure 6. Relays grouped relative to voltage pick-up in springs

operating voltage and the pressing operation continued until the contacts again operate. It only remains to seal the relay at the outer rim of the header.

These small relays have a breakdown voltage of about 1000 at ground level and half that at 130,000 ft. When dry, insulation resistance exceeds 1000 M ohms.

High rigidity to combat vibration is obtained in any but the operating plane, along the axis of the relay, which is provided for by the high force/mass ratio of the armature of about 300:1, resulting in a high g relay by virtue of the small weight of the moving parts.

The static operating characteristics of this relay are shown in oscillographic form in *Figure 5*, in which it can be seen that the relay operates in about 2·0 ms, including transit time and bounce, and releases in about the same time. Contact bounce is at no time longer than 1 ms. The capacity between parts is negligible, being less than 1 pF at 1 Mc/s.

Vibration Tests

Relays tested up to 2 kc/s have withstood acceleration of up to 100 g as is shown in *Table 2*. Limitations of vibration equipment applied as previously mentioned.

The natural resonant frequency of the armature and springset assembly is probably in the region of 4·2 kc/s.

Table 2

G	*Freq.* (*c*/*s*)
50	300–600
60	600–700
70	700–800
80	800–900
90	900–1000
100	1000–2000

Life Tests

Life tests switching two relays of similar type at a speed of 42 ops/s have given lives of well over 10×10^6 operations. Other tests switching loads of $\frac{1}{2}$ A 30 V d.c. at a speed of 60 ops/s indicated a capacity to switch up to 15×10^6 operations, and further tests switching a negligible load have exceeded 40×10^6 operations. This relay is now flying in auto-pilot equipment and giving a good account of itself. They are available for operation at various voltages from 3 to 50.

Semi-conducting Switch or Micro-relay

In America great interest is now being shown in static switching relays, partly because of the introduction of semi-conductor components such as transistors and diodes in micro module equipment and partly because of their great difficulty in meeting high *g*'s in orthodox relays.

In business machines, computers and radar circuits there is some element of overlap in switching characteristics between electromagnetic relays and semi-conductors. It is not only necessary to determine the circuit requirements before deciding which component to use, but also the price and relative fault liability of the numerous components in the complete semi-conductor switching unit must be compared with the single relay.

For instance, to replace a single-make relay, it may require two resistors, two capacitors, two diodes, two transistors, and a pulse transformer. The dimensions when plotted would be about 1 in. × 1 in. × 0·6 in. This represents a great cost, considerable volume and a reliability dependent upon the number of individual components. Compare this with the micro-relay already mentioned which is only 0·3 in. dia., 0·47 in. long, and weighs only 2·5 g.

It was once thought that the vacuum tube or valve would replace the relay for switching purposes but this did not happen. The transistor eliminated many of the undesirable characteristics of valves such as power requirements, heat dissipation and size, and so again one hears it said that transistors will supersede relays. It is possible that the opposite is true, and that the transistor circuits, like the valve circuits before them, will promote the sale of the right type of relay.

Let us examine the situation in detail. The ideal switch should have most, if not all, of the following characteristics: (1) low resistance in the *make* state; (2) infinite resistance in the *break* state; (3) long *reliable* life; (4) be capable of withstanding severe environment—humidity, hot and cold, vibration and shock; (5) low operating power; (6) fast operating speed; (7) switch a variety of loads; (8) no bounce; (9) smallness and (10) cheapness.

How do these two devices measure up to these ideal requirements?

Depending upon the circuit arrangement for the semi-conductor package, the *make* resistance might be between 1 ohm and 150 ohms and the *break* about 1 to 10 M ohms. The relay would have a few m ohms and infinity respectively.

The reliability of a relay is not yet properly defined or determined. Ideally, the reliability factor of a relay should be related to the first failure of a contact to properly close or open a circuit. The literature indicates that relays used in International Business Machine equipment have an average reliablity of 1 failure in 5×10^6 operations, but

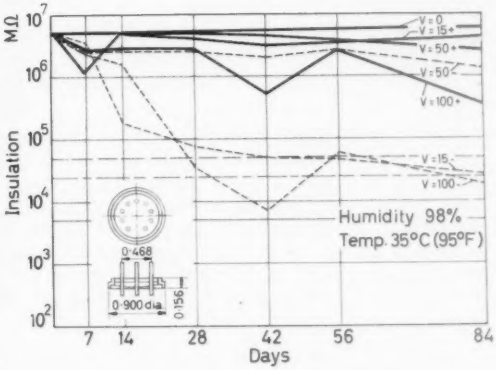


Figure 7. Erosion of 9-pin glass/metal header under tropical conditions

failure was not defined. Other literature indicates that failure of relays is highest during the first 5000 operations and then remains constant till the end of its useful life. The methods used to determine

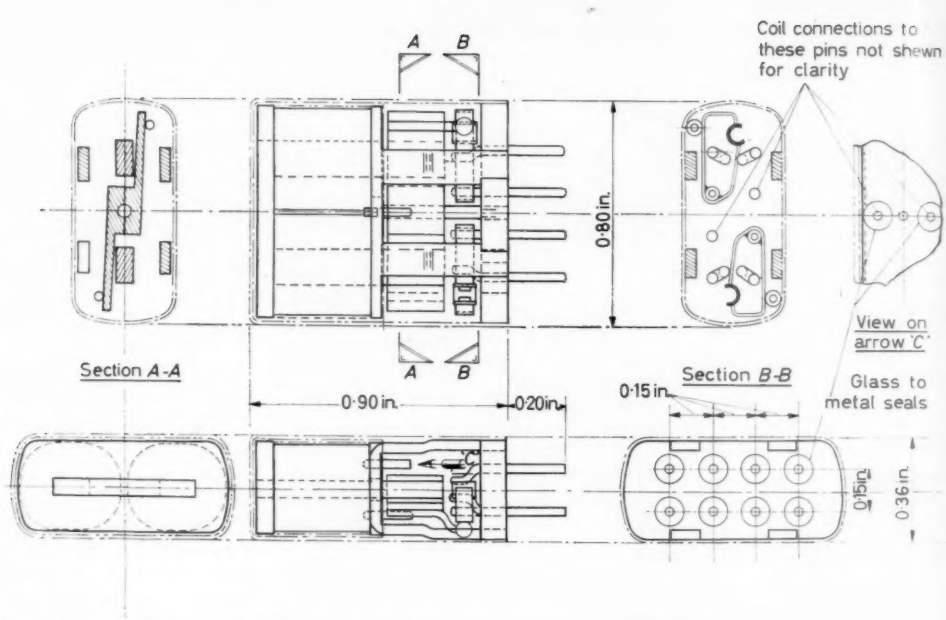


Figure 8. - Postage stamp relay (Courtesy Fortiphone Ltd)

failure, *i.e.* the test circuit, voltage and current limits and failure point, were obviously different in the two cases.

On the other hand, the life of most of the components in the semiconductor package is based on hours of operation and the transistor life, under ideal conditions, might be very high. One failure in 10×10^6 transistor hours has been quoted, but what does it mean, and what would happen under severe service environment? In such environment the reliability of the package might well be reduced to zero.

The advantages of semi-conductor devices are that they have low operating power, (24 mW for the circuit indicated) and high speed of operation (in the μs region). Relays require considerably more power, about 100–150 mW depending upon their volume, and their speed is in the region of a few ms. The current carrying capacity of transistors now compares quite favourably with the light and medium load switched by relays—about 2 A at 30 V d.c. Most relays, unless specially designed, as already mentioned, have a few ms bounce, whereas the semi-conductor switch has none.

The micro relay, which has been used as a comparison, has a single changeover contact in a volume of 0·025 in³. This can be directly compared with a single make, semi-conductor switch having a volume of 0·6 in³ *i.e.* 24 times bigger.

Both are new devices and will undoubtedly undergo a reduction in price, but at present the semi-conductor package described might be put at six times the price of the micro relay.

Induced transient voltage pick-up, intermittent contact failure, and disconnected or shorted coils may beset all but the very best relays, but offsetting these criticisms one might say that relays can now be made to withstand ambient temperatures of 125°C high humidity, and the very high shock and vibration levels met with in modern weapons.

The main disadvantages of semi-conductor switches at present are their inability to withstand

high ambient temperature, and that they may require comparatively complicated power or control circuits. Transient voltage peaks circulating in the circuits may reduce their reliability by destroying the transistor junction.

Transient Voltage Pick-up

A problem related to the shape of a relay is that of induced voltage pick-up in the springs. Upon the release or disconnection of a relay, a high frequency oscillation has been noticed to circulate in the contact circuit of the relay in question. Investigation disclosed that the voltage picked-up was in the general form of an r.f. voltage of about 1 Mc/s, the envelope of the pulse containing higher and lower frequencies some of which lasted for as long as 300 μs.

Relays were classified into the four groups shown in *Figure 6* and results of pick-up under varying conditions are shown in *Table 3* which shows that proper earthing of the relay is effective in reducing pick-up. Resistance in series with the coil should be avoided; parallel resistance is advantageous.

Particular note should be taken that relays with springs lying parallel to the axis of the coil, groups 1 and 2, have higher induced voltages than those with contact assemblies as in group 4, where the contacts are more isolated from the magnetic field.

Multiple Glass/Metal Headers

Another problem now being investigated is the cause and rate of erosion of glass/metal seals under conditions of high humidity and standing d.c. voltage between conductors and conductors and frame. It would appear that low insulation is brought about by conduction along the moist surface resulting in electro-chemical action at the anode and cathode. Corrosion of the metal parts also assists in the lowering of insulation across the glass.

In the first case the glass itself is sometimes eaten away by electrolysis and in the second case conductive tracking lanes are set up which, if removed, leave the glass in as good a condition as before the test. A typical result of a 9 pin glass/metal header is shown in *Figure 7*, in which it can be seen that it is not necessarily a high voltage which creates the most havoc, but a medium voltage, and the ' direction ' of the voltage plays an important part. This investigation is proceeding.

Postage Stamp Relay

A relay of the form commonly referred to as ' postage stamp ' has been specifically designed for use in guided missiles and developed for R.R.E. by Fortiphone Ltd. It is a direct replacement for the many American relays of this shape, several of which are now being copied in this country.

Table 3

Group	Series Resist.	No	No	No	Yes	Yes	Yes	Yes	Nominal Coil Voltage d.c.
	Can Earthed	No	No	Yes	No	Yes	No	Yes	
	Mag. crt. earthed	No	Yes	Yes	No	No	Yes	Yes	
I	P.O. 3000	50V	5V	—	50V	—	5·0V	—	48
	G.E.C.-S.M. 5*	0·72	—	0·07	0·8	—	—	0·12	24
	S.T.C. S.M.5A*	1·4	—	0·4	2·9	—	—	0·5	12
II	Siemens H/S	10·0	3·6	—	40·0	30·6	10·0	8·6	6
III	S.T.C. 60-LA-IA	4·4	—	0·8	8·4	—	—	0·8	28
	Erics. Type 2*	4·0	—	0·2	5·4	—	—	0·5	24
IV	Magnetic* Devices 335	0·6	—	0·15	0·65	—	—	0·1	24

* Can and magnet crt. permanently connected

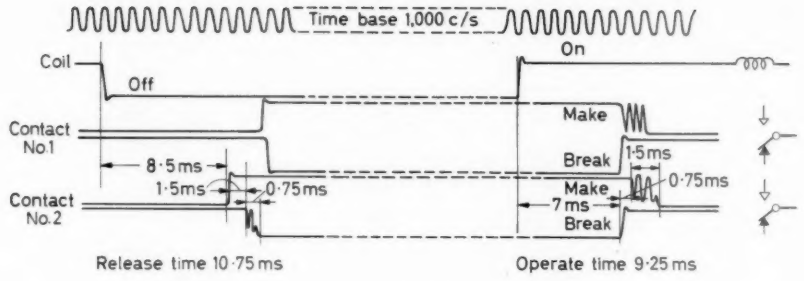


Figure 9. Static operating characteristics of Fortiphone 2 c/o G.W. relay operated on nominal voltage. (Courtesy Fortiphone Ltd)

With few exceptions, these foreign relays require at least 1 W to operate them satisfactorily, but the relay shown in *Figure 8*, and to be described, operates in 150 mW (unpolarized) and about 40 mW in its polarized form at a temperature of 125°C.

To achieve maximum reliability the relay uses the principle of a separate compartment for the contacts, which was satisfactorily achieved in the micro-relay previously described. Since a greater volume is available, and because two coils of equal diameter and length produce the same ampere turns for half the power of a single coil, it was decided to adopt a double coil design.

The relay consists of a single-piece U shaped electro-magnet between the poles of which is pivoted the armature. Great care has been taken to achieve the optimum in core size and armature width to achieve the greatest sensitivity and an enlargement of the top of the yoke increases the pull considerably. It also acts as a heat sink for cooling purposes.

The two changeover contact arrangement can incorporate the usual split cantilever springs, or be of the constrained spring type which withstand very high *g* vibration and acceleration more successfully. The constrained spring system used actually increases the contact pressure of the ' break ' contact just prior to its operation. This is a most satisfactory achievement.

An oscillographic presentation of the static operating characteristics of this relay is shown in *Figure 9* in which the maximum bounce is seen to be less than 2 ms at any time. It is sometimes less or even non-existent. The relay operates and releases in 10 ms and has been vibrated up to 2 kc/s at an acceleration level of 100 *g*.

Arming or 'Stabilized Relay'

In another form in which there are four changeover contacts and four coils, the relay withstands torsional vibration. This is achieved by the use of a stirrup and ground-bar device which links the two armatures in such a way that both armatures operate together and at the same instant. Since both armatures are dynamically balanced and rotate in opposite directions, any vibration, whether linear or torsional, is cancelled out. Essentially it comprises two of the relays shown in *Figure 8*. The multiple coils can be used to give greater coil reliability. As many as three of the four coils can fail without the relay ceasing to function.

It is foreseen that certain parts of guided missiles will require components with exceptionally low failure rate. Such circuits as fusing, atomic warhead arming, and telemetry circuits require a failure rate better than 0·01 per cent, and as low as 0·001 per cent. This ' stabilized ' relay, has been developed as the ultimate in reliability both so far as relay contacts are concerned and also with regard to coil and reliability.

Indications to date show that special quality relays will be in ever greater demand, and, at least until the solid-state circuit arrives, their sales will increase, and an equipment designer may eventually be loath to part with a component he has learned to ' fit and forget '.

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SURVEY

The Physical Society Exhibition

Every year this exhibition gets larger and larger and a phenominal number of instruments for synthesizing, analysing, purifying, preparing, comparing and measuring such diverse attributes as neuro-muscular function, low attenuation in wave guides, atmospheric pollution, *etc.* were exhibited this year.

Hilger and Watts showed a new prototype photoelectric microptic polarimeter (*Figure 1*). The optical scale is read visually by a microscope, as in the original version, but a photoelectric setting has been provided for the extinction angle. It is claimed to have an accuracy of about 0·005° over 90°, and a precision of ±0·002° can normally be obtained, without fatigue or faulty judgment. The instrument has a double-beam-in-time optical system, obtained by modulating a beam of plane polarized light with a crystalline quartz plate on the end of a controlled vibrating reed. Out-of-balance signals are annulled by manual rotation of the analysing prism, and an attached scale shows the concentration of a sample. Polarimeter tubes up to 400 mm long can be used.

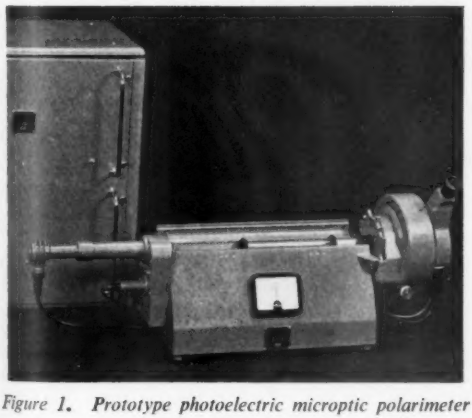


Figure 1. Prototype photoelectric microptic polarimeter

Ferranti in collaboration with the Aeronautical Directorate Laboratories, have developed a recording extensometer for long term creep testing at high temperatures. Extension of the specimen is detected photo-electrically from Moiré fringes produced by two small sections of diffraction grating. A four-phase signal is fed to a transistor power amplifier which drives one axis of a pen recorder. A synchronous motor drives the other axis, and the extension, greatly magnified, is plotted against time.

The Research Laboratories at Mullards have been investigating the potentialities of very thin magnetic film (about 1000 Å) as fast bi-stable memory elements for computors. A thin nickel–iron film evaporated in a uniform magnetic field exhibits uniaxial anisotropy. When influenced by a magnetic field perpendicular to the anisotropy axis and weaker than the anisotropy field, the magnetic vector has two possible stable states. This allows information to be stored in binary form. Transition between the two states, under the influence of a drive field parallel to the anisotropy axis, may be accomplished in tens of millimicroseconds.

A simple method of determining the viscosity of gases and liquids at high temperatures and pressures has been devised by the Coal Tar Research Association; a steel ball is allowed to roll between two contacts in an inclined steel tube filled with the test fluid, and the time of roll is measured by an electronic chronometer. At low roll speeds under laminar flow conditions, the time of roll is proportional to the viscosity of the fluid.

The Wool Industries Research Association exhibited their automatic partition chromatography apparatus which separates and analyses a mixture of radioactive substances. For example a mixture of amino acids from a protein hydrolysate is partially separated by chromatography on an ion exchange resin. The effluent is brought to pH 9·2 by the continuous addition of a phosphate–borax buffer, and pumped through a small column of copper phosphate containing Cu^{64}. The effluent from this column, containing the labelled complexes of the amino acids, is passed to the machine which draws a chromatogram by plotting the activity in counts per minute against the fraction number from the initial separation.

The British Hat and Allied Feltmakers Research Association employ a very up-to-date technique to measure the 'substance' or local weight per unit area of felt hat bodies and hat shapes. The equipment used is a standard Ekco Nucleonic Thickness Gauge, Type 565. The measurement is by the amount of β radiation absorbed—the source is a circular disc of Sr^{90} with approximately 15 mc strength and a diameter of 26 mm, and the area of felt scanned is 28·5 mm diameter. The weight of hat felts is in the range 100–3000 g/m² which makes them suitable for measuring by this means.

L.C.C. Research

The Annual Report of the Scientific Adviser to the L.C.C., Dr S. G. Burgess, makes most impressive reading. The Scientific Branch of the Public Health Department has a research team of sixty-one, including thirty graduates, working in the laboratories in County Hall and at the Northern and Southern

Outfall Works. They carry out research and give advice to many of the public service departments of the L.C.C. With the Chief Engineer they investigate different aspects of sewage treatment, sewage disposal, and river pollution, and they make regular observations on air pollution ; they check that water treatment in public swimming baths is efficient, that the ventilation in Blackwall and Rotherhithe tunnels is adequate and they give advice to the London Fire Brigade on precautions and investigations including the adoption of an audible warning device which, if a fireman wearing breathing apparatus is in difficulties or unconscious, emits a shrill sound to draw attention to him.

There is little basic research done, and much of the work is for inspection and comparison of products. Many commerically available products are analysed—detergents, foods, paints, disinfectants, lubricants, polishes and building materials. Some of these analyses are routine inspections to ensure that the products conform with legal requirements and specifications, and some are to test and compare materials used by different departments of the L.C.C.

Polymer

The first issue of Polymer, a new quarterly journal on the chemistry, physics and technology of high polymers, will be published on March 14. The editors are Dr C. H. BAMFORD of Courtaulds, Professor C. E. H. BAWN of Liverpool University, Professor G. GEE of Manchester University and Dr ROLAND HILL of I.C.I. Fibres Division. The publishers are Butterworths Scientific Publications.

Reinforced Timber

The life of wooden props in mines is short as they deteriorate quickly due to damp conditions. The most usual way of prolonging their life is to treat them with creosote, but this is highly inflammable.

The Tin Research Institute has experimented on a method of prolonging the life of timber by impregnation with organotin compounds. This was effected by immersing the logs in a tank of hot aqueous solution of triethyltin hydroxide and leaving them there overnight. They were then tested by erecting them in a mine, side by side with 'control' untreated props. The treated and untreated props were examined at intervals over two years by the end of which time the untreated props were so rotten that a sharp knife would sink right in if they were stabbed, and they had splintered and flaked; the treated props were completely sound except for some lengthwise cracking (see *Figure 2*). Tests were made in several mines, over varying times, and showed similar results.

Figure 2. Untreated timber (LEFT) *compared with treated timber* (RIGHT) *after 3½ years in Geevor Tin Mine, Cornwall.* (*By courtesy of the Tin Research Institute*)

Triethyltin hydroxide was used for the tests because it is moderately soluble in water: however, it is not available commercially and is an unpleasant substance to prepare and handle, and the Tin Research Institute are now experimenting with tributyltin oxide and triphenyltin acetate, neither of which is sufficiently water soluble. However, they are soluble in organic solvents and tests are now being carried out using emulsions of water and solutions of tributyltin oxide in, for example, paraffin, kerosene or fuel oil.

Computer Section for U.K.A.E.A.

Because the price of trial and error experiments is so high in the nuclear power industry, it is necessary for every precaution to be taken to ensure that reactors should be planned and operated with the maximum efficiency. In order to facilitate such planning, U.K.A.E.A. constructed their neutron 'time of flight' laboratory at Harwell (Research (1959) **XII** 483) and they have also established a Computer Section in the Central Technical Services at Risley. This is the largest general-purpose computing centre in Europe, the major tools being two

digital computers, a Ferranti 'Mercury' computer and an I.B.M. 704, and an Electronics Associated PACE analogue computer. For simple problems there are hand calculating machines.

Problems from any branch of U.K.A.E.A. are sent to the appropriate section of the Central Technical Services and, when necessary, passed to the Computer Section. The calculations may relate to the design or operation of a nuclear reactor; in design, for example, performance calculations for reactors of widely varying specifications are carried out and the most efficient chosen; and for operation power fluctuations throughout the core examined by calculating the local power density at over one hundred points within it.

The analogue computer PACE is able to solve time-dependent problems. The problems can be modified within the time specified, as is possible during reactor operation, and the effect on the solution demonstrated by the computer.

An automatic data-transmission link has been established with A.E.R.E., Harwell, and will shortly be established with Winfrith Heath. The I.B.M. 704 uses a punch-card system, and these cards are teleprinted direct from Harwell, and the computer's calculations transmitted back in the same way. Thus Harwell can keep a continuous check on the results and, if necessary, alter a programme in midstream.

Cleanliness

One of the problems in the manufacture of miniature components is that to achieve the dimensional accuracy required a very high standard of cleanliness is necessary. British Manufactured Bearings Ltd, who are manufacturers of miniature precision ball bearings with bore diameters down to 0·040 in. have met this problem by forming a subsidiary company who manufacture pressurized assembly cabinets (*Figure 3*); a fan draws air into the cabinet through a filter, and as the outlet is smaller than the channel of air in the cabinet the interior is slightly pressurized, thus preventing air-borne pollution from entering through the front or working aperture of the cabinet, and also forcing any particles which may be inside to the base.

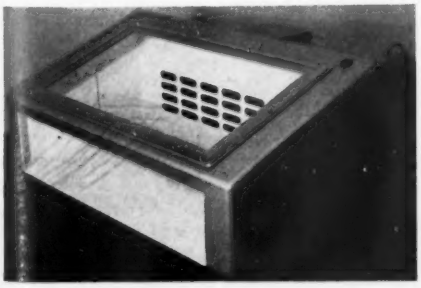


Figure 3. Pressurized assembly cabinet

U.K.A.E.A. Films

Three films made by ACE Distributors, the film unit of the U.K.A.E.A., were shown to the press on January 28. The first one, Dounreay Fast Reactor, showed the construction of the experimental fast reactor at Dounreay. The photography in this film was magnificent and the scenes of the interior of the sphere before the reactor was put in most impressive.

The other two films were both in colour. One was an instruction film for technicians at Calder Hall on the process of refuelling. The other, which was of more general interest, was of the laying of the pipeline from Winfrith to the sea for the disposal of radioactive waste. The underground line from Winfrith to the sea consists of two pipes, a six inch diameter pipe inside a twelve inch one. The radioactive waste passes along the inside one, and other waste down the outside one. The process of welding, descaling and radiographing the joints in the pipe before they were covered with bitumen was shown. The waste has to be pumped up from Winfrith until it reaches the highest point above sea level, and here there is a double tank—again with the radioactive waste inside. The waste then flows by gravity down to the sea. Near the shore the two pipes divide and the non-radioactive waste is canalized into pipes running 50 feet out to sea, whereas the radioactive waste is released 2 miles out from the shore. The film shows the blowing up of five underwater reefs which lie between the shore and the two mile point, and there is some very good underwater photography of the sea bed and of the frogmen and conventional divers who helped in the prospecting, laying and checking of the pipes. The steel pipes were covered in concrete before being laid to prevent abrasion, and whilst they were being towed out to sea they were kept clear of the sea bed by buoyancy tanks, which were released and collected when the whole two-mile length was laid. Dispersal equipment was connected at the end of the pipe. The laying of the underwater pipeline took only five days.

The Bathyscaphe

The summit of Everest is 29,150 feet above sea level and M. Piccard has now been down 37,800 feet below the surface in his bathyscaphe, making a total of 66,950 feet or nearly 13 miles. The radius of the earth is approximately 4,000 miles. Here, at least, Jules Verne is still well ahead of us.

BOOK REVIEWS

Biochemistry of Antibiotics

K. H. SPITZY and R. BRUNNER (*Eds*)

(*xii + 239 pp; 9¼ in. by 6 in.*)

London: Pergamon Press. 68*s*

IT IS instructive to compare the First International Congress of Biochemistry held in 1949 in Cambridge with the Fourth held in 1958 in Vienna. The Cambridge Congress was divided into twelve sections and the abstracts of the communications read to these sections were published in a volume of some 600 pages, surplus copies of which were sold after the Congress at a nominal price. There were, in addition, two Congress Lectures which were later published by the Biochemical Society. By contrast, the proceedings of the Fourth Congress—comprising the Symposia, the Colloquia, the Transactions of the Plenary sessions and the Abstracts of the papers given to the eighteen sections—are now being published, in fifteen volumes (price £48) by Pergamon Press.

The symposia occupy some twelve of these volumes and this illustrates very clearly the change in emphasis of the Congress. The symposia are in fact oral reviews of selected aspects of biochemistry; they thus provide the non-specialist with the opportunity of hearing experts discuss the growing points of their subject and the large audiences they attracted emphasized their importance. However, when the symposia are published in book form the subtle contact between the lecturer and his audience is lost and one is left with a review which must be compared with those published in the review journals.

The volume under review (Volume V in this series) is edited by SPITZY and BRUNNER and contains the nineteen papers read at the Symposium on the Biochemistry of Antibiotics along with some of the discussion which followed.

In the first article WAKSMAN reviews briefly the Classification of the *Actinomycetes* listing the generic criteria he adopts. He also gives some useful tips on the recognition of species within the genus *Streptomyces*. VAN SUMERE and MASSART describe the chromatographic procedures they have used for the separation and identification of germination inhibitors from plants—phenolic acids and coumarins. DESPOIS, in two pages, gives his views on the mode of action of these compounds, whilst SAALBACH and KÜSTER describe some experiments they have performed on the effect of phenolic acids on the growth and metabolism of plants.

Undoubtedly the most thoughtful article in the book is that by ABRAHAM and NEWTON who, in a very short space manage, successfully, to outline the structural and biogenetic relationships of the antibiotics. At present very little is known about the synthesis of these compounds but the authors point out that many of them are built up from ' substances that play an essential metabolic or structural rôle in the life of micro-organisms . . .'.

There are some ten articles which, according to the blurb on the dust cover, purport to deal with ' the effect of antibiotics on the life process '! The contributions of both DI MARCO and HAHN are concerned with the mode of action of antibiotics on susceptible organisms. Both authors go over well known ground and there is a certain amount of duplication. The therapeutic use of mixtures of antibiotics is considered both by JAWETZ and by GALLEGO; FINLAND describes experiments on the development, by a number of bacteria, of cross resistance to related antibiotics.

Certain antibiotics which have been shown to promote the growth of domestic animals and feeding stuffs, are now supplemented with small amounts of the more effective antibiotics, particularly the tetracyclines and penicillin; this fascinating topic is reviewed by BRUGGEMANN. Tetracyclines are widely used in the United States and Canada, but not as yet in Britain, as food preservatives. There are two main problems here: firstly, the possible effect of the antibiotic on the consumer, and secondly, the possibility that the wide spread, indiscriminate use of these compounds may lead to the development of resistant strains of pathogens. CAREY, in his article discusses the evidence which supports the view that these compounds, in the amounts used, have no deleterious effect on man. He does not discuss the development of resistant strains! The book ends with CHAIN's summary of the proceedings of the Symposium. In this feat of compression CHAIN highlights the main points and at the same time manages to squeeze in a considerable section on the chemistry of the antibiotics, thus reinforcing the contribution of ABRAHAM and NEWTON.

My general impression on reading these contributions, which are very uneven in quality, is that time was insufficient to permit the contributors to develop their subjects. Because of this the articles tend to be slight by comparison with the available reviews on similar topics. Consequently I cannot subscribe to the view expressed on the dust cover that ' It will be invaluable to all concerned with this beneficial field of research '. Nor, writing at the end of 1959, do I accept that—' The book is of tremendous topical importance, especially to present day medical research . . .' S.R.E.

Experimental Nuclear Physics

E. SEGRE (*Ed.*)

(*ix + 811 pp; 9¼ in. by 5¾ in.*)

New York: Wiley; London: Chapman and Hall. 184*s*

THIS volume is the last of a trilogy whose aim, as the editor hints in his preface, is to become the nuclear physics equivalent of *Handbuch der Physik*. The presentation of four of the five articles in one volume was clearly dictated by their kinship and frequent interrelations.

The first, by SEGRE, is mostly concerned with the statistical phenomena encountered in recording radioactive decay. This article is valuable for its clarity of exposition and for what is, as far as the reviewer can recall, the only modern summary (regrettably brief) of methods for measuring decay constants. The latter can

readily be recommended to undergraduates and other non-specialists in nuclear physics.

The next three articles deal with the original three musketeers of nuclear physics; the alpha, beta and gamma rays. Alpha radioactivity in all its aspects is dealt with by G. C. HANNA who includes an interesting account of experimental methods and in particular limiting processes in the associated electronic equipment. The overall impression one gains is that while experimentally there are some details which need tidying up, the real trouble lies in the unsatisfactory state of the theory.

M. DEUTSCH and O. KOFOED-HANSEN cooperate on articles entitled Gamma-Rays and Beta-Rays. These will inevitably be compared (favourably) with the relevant articles in the Siegbahn volume *Beta and Gamma Ray Spectroscopy*. Oddly enough they were originally completed at about the time of publication of the latter (1955) and have had to be brought up to date since. The emendations are not serious in the case of gamma radiation but parity non-conservation has necessitated extra writing in the pages dealing with beta decay. Despite loose ends left by this, here is the distilled essence of beta and gamma ray spectroscopy in a highly palatable form. Here too, the omission from the appropriate part of Volume I of a serious account of scintillation detectors, is repaired.

The final section is set apart from the others. Particle Accelerators must find a place in a book of this nature, though it would be in keeping with the rest of the volume if the energy range below, say, 100 MeV had been discussed. As it is, E. M. MCMILLAN's article covers the whole energy scale available at present, but contains little or no account of beam and target techniques. A special feature is the excellent collection of photographs showing many aspects of accelerator design including historic apparatus. These are set off by an account such as can only be given by a man who has been 'on the inside' since the early days. One thus learns much about the things which did not work as well as those which did, and it is often difficult to decide which is the more valuable for the experimental physicist, whatever his speciality.

Presentation, diagrams and indexing are exemplary and the valuable lists of references for each section represent much painstaking work. F.C.F.

The Electric Arc

J. M. SOMERVILLE

(ix + 150; 6¾ in. by 4¼ in.)

London: Methuen. 12*s* 6*d*

PROFESSOR SOMERVILLE has provided in this monograph a most helpful introduction to the present knowledge of the arc discharge. He has succeeded in the difficult task of surveying the very extensive post-war literature on the arc, and by focussing attention on some important problems indicates to the student that the arc is still a field worthy of further investigation.

The monograph comprises an introductory chapter describing the essential arc characteristics and noting some basic discharge parameters, and main chapters on the properties of the steady state long column and electrode-column junctions. In describing the long column emphasis is laid correctly upon the different methods of temperature measurement, upon the modes of energy transfer and loss, and upon the important parameters of electrical and thermal conductivity. The measurement of the electrical characteristics of the long column is also described. The possibility of thermonuclear reactions in the arc is also indicated.

The best section of the monograph is undoubtedly in the chapter on electrode-column junctions. Here, Professor SOMERVILLE provides an admirable survey of the many intriguing experiments and theories on the cathode mechanism. The account of the thermionic, thermal-field and field arcs and the discussion of the contraction theory are lucidly stated. The features of retrograde motion are clearly listed and proposed theories discussed, as are also the phenomena and theories of the anode. The chapter ends with a section on electrode and plasma vapour jets.

The last third of the monograph is concerned with the approach to the static arc. Although a description is given of the production of arcs *via* glow to arc transitions, by electrode separation and by high field emission, a considerable section is given to the spark discharge as a means of approach to the arc. The development of the spark channel, theories of its expansion and methods of measurement are described. It is to be hoped that students and research workers will not be misled by the presence of spark theory in an arc monograph into a confusion of these distinctive discharges. H.E.

Proceedings of International Conference on Nuclear Physics, Low Energy Interaction and Nuclear Structure

MME. P. GUGENBERGER (*Ed.*)

(xxiv + 950 pp; 9¾ in. by 6¼ in.)

London: Crosby Lockwood. 140*s*

SINCE the war there have been several international conferences on low energy nuclear physics under the auspices of the International Union of Pure and Applied Physics. The one at Glasgow in 1954 resulted in a volume of conference proceedings which was slim enough to be carried in an overcoat pocket. Succeeding conferences have produced volumes which, though larger, are still of tolerable size. The book under review is half as long again (in number of pages) as that reporting the Rehovoth Conference and must now be placed in the *jumbo* class.

The book, as its title shows, is for specialized specialists in nuclear physics. It contains two sorts of papers, nearly all of which deal with phenomena occurring at energies less than 100 MeV. Taking Part 2 first, as this constitutes the bulk of the book, one finds original papers presented more or less on the lines of journal publications and grouped under subject headings: nuclear reactions, nuclear forces (sixty-nine papers); photonuclear reactions (twenty); nuclear models and

structure of nuclear matter (thirty-six); weak interactions (thirteen); nuclear sizes and unclassified papers (eighteen).

Each of these aspects of nuclear physics was discussed by a coordinator who was responsible for a review paper which, together with the subsequent discussions, appears in Part 1 at the beginning of the volume. It is a monument to the work of MME GUGENBERGER and her helpers that the one hundred and fifty or so papers from twenty countries have been reduced to only two languages (French and English) and less than a thousand pages.

If the average nuclear physicist is anything like the present reviewer, he marks the papers he really wants to read, and is then seduced into browsing. The discussions, reported verbatim, are fascinating places for finding unexpected gems. The thought occurs, though, that eventually speakers at such conferences will rebel at having their spontaneous emissions recorded for all time.

The work as a whole, dedicated *in memoriam* to FREDERIC JOLIOT who opened the conference, presents an interesting picture, at a given instant of time, of the growing but maturing subject of nuclear physics. How much of it will be of absorbing interest and usefulness in four years time one does not know, for by then presumably another group of volumes, even larger and more verbatim in character, will have appeared. Only the very rich and very keen will pay £7 for such a volume. There is certainly a need for publication of the proceedings of conferences where important work is presented, but surely some cheaper format is needed. Parts 1 and 2 of the present volume might have been issued separately, perhaps paper-backed in the best French tradition. As it is, most interested workers will let the library of their organization buy a copy and then take it 'permanently on loan'. F.C.F.

Organization of Building Sites

R. C. SANSOM

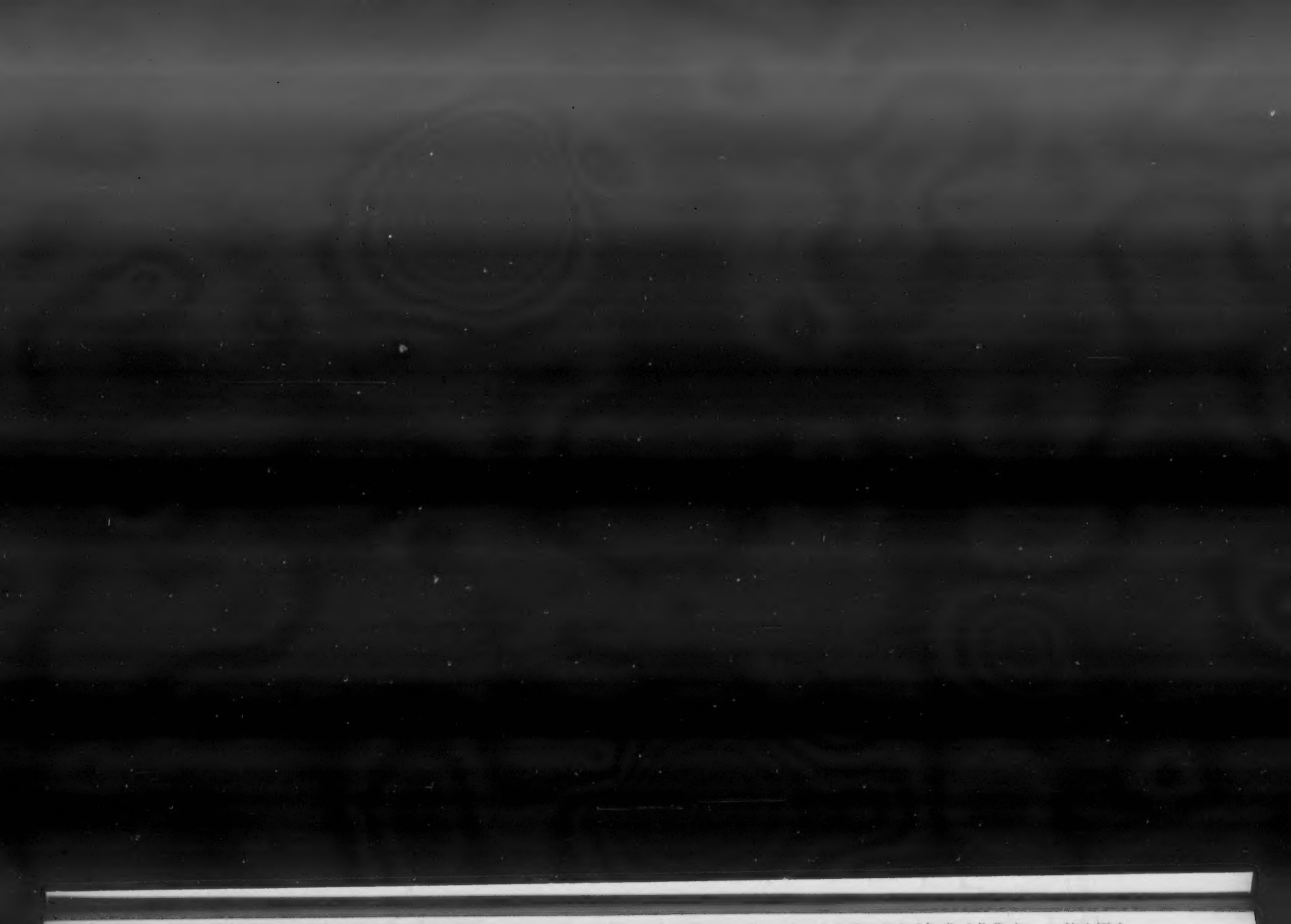
(*x* + *186 pp; 9¾ in. by 6 in.*)

London; H.M.S.O. 21*s*

THE Building Research Station has carried out a project on behalf of the European Productivity Agency (302/1) the results of which are published in the latest National Building Study Special Report No. 29 dealing with the Organization of Building Sites. The work has involved visits to twenty-six firms widely spread over nine European countries, and the results obtained are contained in the thirteen essential chapter headings plus an introduction, summary and appendices.

It is only fair to recognize the book within the context of a report to the E.P.A. and the development of chapters as complete reports in themselves and, thus, to subdue the petty irritation of the frequent anonymity of the countries, particularly where comparisons might obviously be drawn, and to accept the bilingualism of many of the charts, forms and diagrams, even if these thus are more difficult to read. The report will clearly have an appeal over a wide front on the general subject and also some specialist attention on the specific chapter headings. It is never very clear to whom the book is addressed and there is some confusion between the excellent introduction for the student and the inexperienced, and the many rather complicated methods and details which are described. There are really two forms of text involved and perhaps later the B.R.S. might edit the document into two more useful documents. The first could be the general introduction to the various sub-divisions with the now well-known precepts concerning contract planning, and the second could include the advanced details which would be of great value in starting a chain reaction of study in building management. Such chapters as Incentive Payments, Cost Control of Sites, and Cost of Output Analyses, are excellent for this purpose. It is also valuable to recognize a wide European picture of problems of supervision, planning and programming of building work and the chapters on these subjects emphasize the problems which develop, evidently nearly universally in countries of similar industrial standard. The report makes clear, too, that much work must go on to improve productivity by a much more advanced study of these planning and supervisory tools.

A very good summary of present inadequacies can be found in the chapter on Welfare. Some site plans of a few of the Danish and Norwegian examples would have been interesting; in fact, when the book is revised, perhaps more attention could be given to the graphs and illustrations, some of which are not up to B.R.S. standard and many of the photographs are not sufficiently informative in detail.

The chapter summaries are useful and highlight interim findings, and if some of these are a little inconclusive and perhaps even rather elementary, they emphasize how much more work can now be done on the background studies of the book. This work could hardly have been undertaken except by the B.R.S. through the E.P.C. and books which follow on specific issues will undoubtedly be influenced by the very valuable and painstaking work of research which is portrayed. It will fortunately be found on the desk of any student of building management and, no doubt, the directors of most contracting firms, and its influence, therefore, in the approach to solutions of many of the questions posed, though not answered, is likely to be great. D.R.H.

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